HYDROLOGY OF THREE EXPERIMENTAL WATERSHEDS IN SOUTHERN FLORIDA

A PROGRESS REPORT

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HYDROLOGY OF THREE EXPERIMENTAL WATERSHEDS IN SOUTHERN FLORIDA - A PROGRESS REPORT[1]

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INTRODUCTION

A prime purpose of experimental watersheds is to ascertain the change in hydrologic response caused by systematic variations in both land use and drainage. Watershed areas tend to be small for convenience and ease of control. But one should be able to extrapolate and, if necessary, transfer conclusions from small watershed studies to complete river basins.

Three such watersheds–Indian River Farms (Florida W-1), Upper Taylor Creek (Florida W-2), and the top portion of Upper Taylor Creek (Florida W-3)–have been maintained since 1951, first by the Research Division of the Soil Conservation Service (SCS) and later by the Agricultural Research Service (ARS). The investigations are made under formal agreement with the Florida Agricultural Experiment Stations and the Central and Southern Florida Flood Control District. Informal cooperation is maintained with other Federal, State, and local agencies concerned with the development of water resources. These include the Soil Conservation Service (USDA), U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, Florida Board of Conservation, Dade County Water Conservation District, and local drainage districts.

The watersheds are located in the Southern Florida Flatwoods Resource Area.[3] Although the three watersheds are similar in all climatic and physiographic factors except area, they differ in degree of agricultural development. This development involves both changes in land use and improvement of drainage.

This publication summarizes the observations made from October 1955 through September 1962 and reports the progress of subsequent investigations using these data. Because this is a progress report rather than a completed investigation, some assumptions and simplifications must be made until additional data can be collected.

Figure 1 shows the location of the watersheds in relation to land resource areas. Figures 2 and 3 are watershed maps showing the instrumentation and principal watercourses of watersheds W-1, W-2, and W-3.

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[3] Land resources regions and major land resources areas of the United States. Map. USDA, SCS, January 1963.

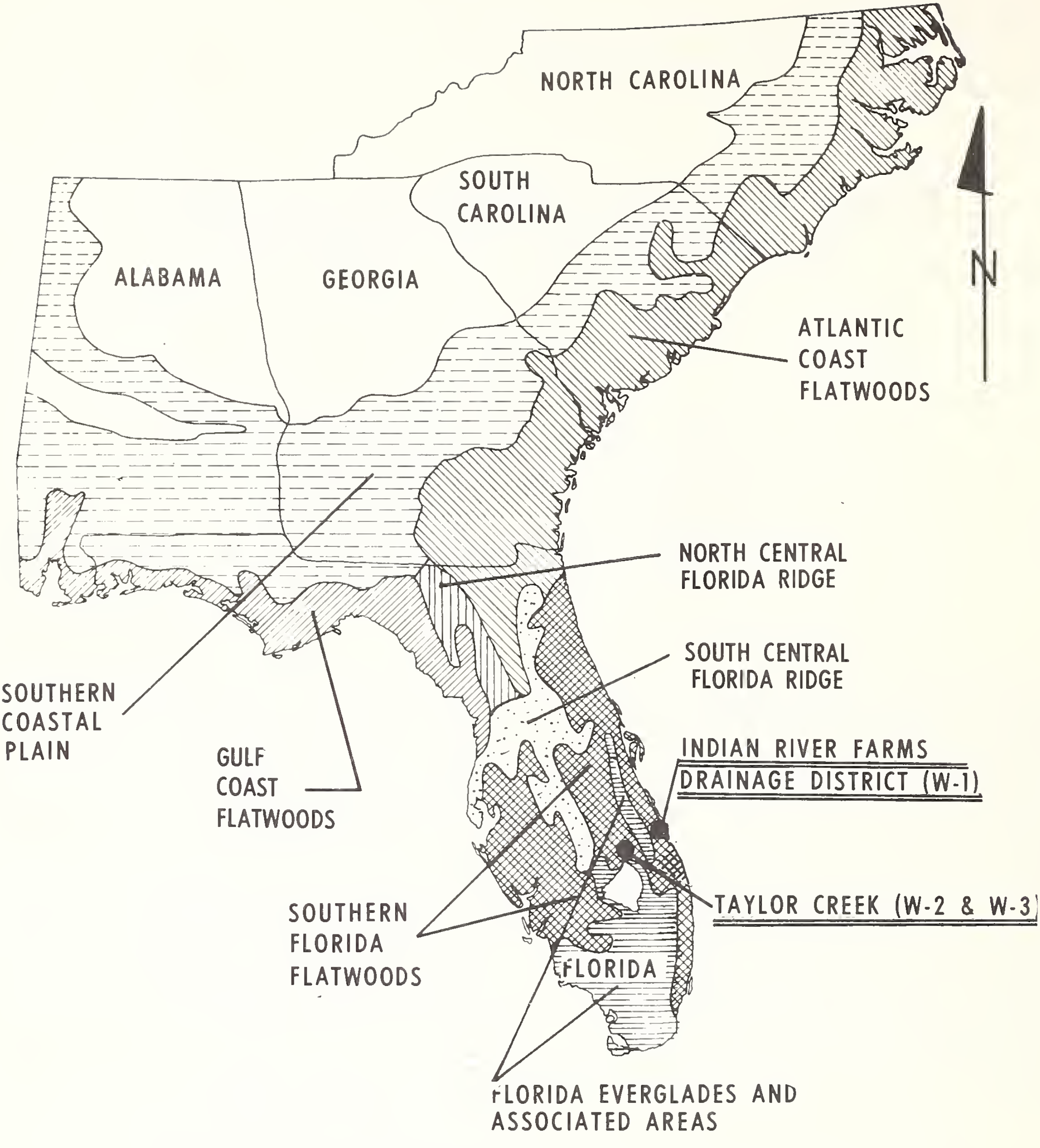

Figure 1.—Location of Florida watersheds in relation to land resource areas.

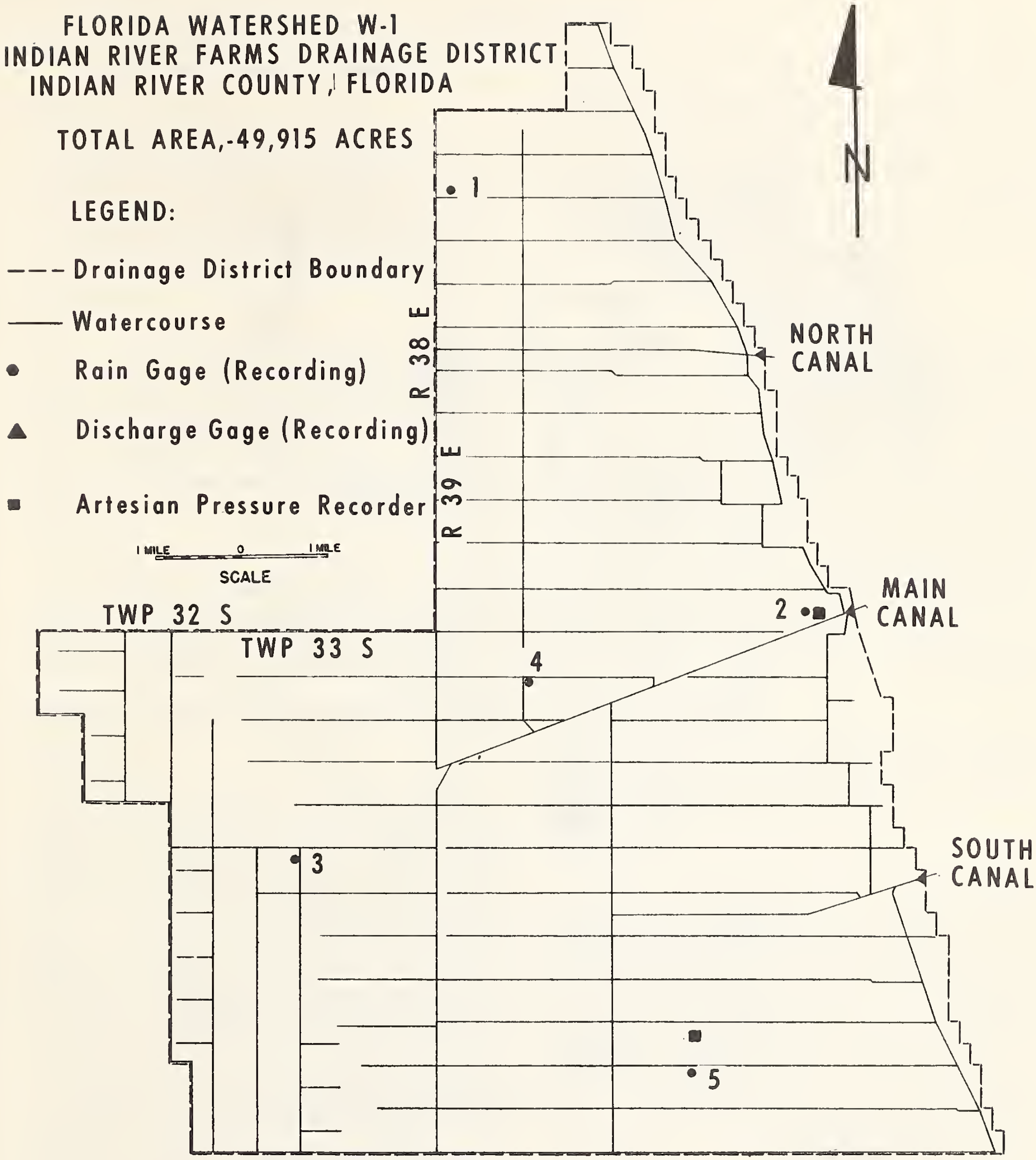

Figure 2.–Indian River Farms Drainage District, Florida Watershed W-1.

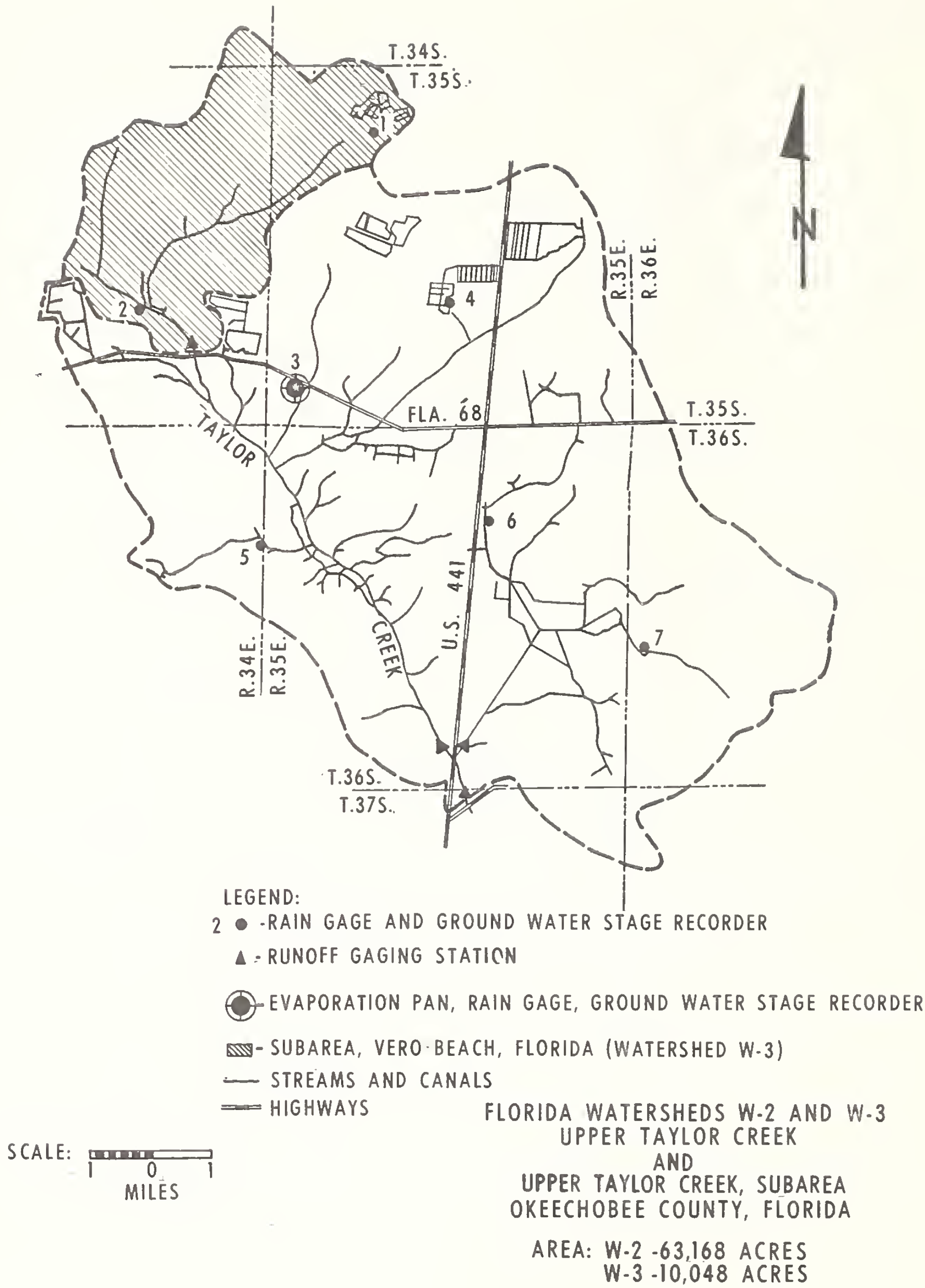

Figure 3.–Upper Taylor Creek Watershed, Florida Watersheds W-2 and W-3.

LOCATION OF THE WATERSHEDS

Florida W-1

This watershed of 49,915 acres (78.0 square miles) comprises the total area of the Indian River Farms Drainage District and lies within Indian River County, Fla. This triangular watershed is approximately 12 miles long, north to south, and 6.5 miles wide, east to west.

Florida W-2

This watershed of 63,168 acres (98.7 square miles) comprises the portion of the Taylor Creek drainage basin situated above backwater influence from Lake Okeechobee. It lies within Okeechobee County, Fla. The drainage basin is broadleafed in shape, about 7 miles wide northeast to southwest, and 15 miles long northwest to southeast.

Florida W-3

This watershed of 10,048 acres (15.7 square miles) comprises the northern portion of watershed W-2. It is roughly rectangular, about 3 miles wide northwest to southeast, and 9 miles long southwest to northeast.

TOPOGRAPHY AND DRAINAGE CHARACTERISTICS

Florida W-1

This area has controlled drainage and irrigation. Nearly all of the area has slopes in the 0-2 percent class, aspect east. Under virgin conditions, the soils were predominantly poorly drained sands, but since water tables have been lowered, internal drainage ranges from medium to very rapid. Surface layers are fine sands, ranging in depth from 12 to 60 inches, with very rapid permeability. Subsoils are organic hardpans, clays, or marls, with much variation in thickness and hardness, and with permeabilities ranging from moderate to moderately rapid. There is little or no erosion. Eighty percent of the lands are in Class IV capability (land of limited productivity suited only for special crops or seasonal usage), and 20 percent are in Class III (productive land requiring intensive treatment for successful cultivation). The entire watershed is a well-maintained drainage district of low relief, shielded from outside inflow by levees. Surface drainage is fairly rapid. The watershed is drained internally by a 420-mile network of canals. Outflow is by gravity through three major outfall canals, and streamflow is classified as perennial and continuous. Radial-gate structures have been installed on all three outfall canals for runoff control and water conservation during the dry season. The controls were installed in the Main Canal and North Relief Canal in October 1954, and in the South Relief Canal in May 1956. Citrus grove land is irrigated by 1,000 to 1,500 artesian wells.

This watershed is generally representative of highly developed agricultural lands of low relief in the Southern Florida Flatwoods. The lands are drained by gravity and artesian irrigation augments rainfall during the dry season.

Florida W-2

This basin is a natural watershed with relatively flat, quasi-karstic topography. The watershed contains numerous ponds and sloughs and there are some ditches for pasture improvement over a minor part of it. The principal watercourse is 15.6 miles long. Aspect is south-southwest and the slopes in the area are nearly all in the 0-2 percent class. Because the soils are friable with high infiltration rates, little surface runoff occurs until the soil becomes saturated. The water table is normally close to ground surface. There is very little soil erosion. Land capability is 88 percent in Class IV, 9 percent in Class III, and 3 percent in Class II (productive land requiring special treatment for successful cultivation). Surface drainage is sluggish; flow is mostly continuous ground water seepage.

This watershed is generally representative of partially improved rangeland with mixed woodland in the Southern Florida Flatwoods. The land is of low relief and is largely under natural drainage conditions.

Florida W-3

This is a natural watershed. Its principal stream (6.8 miles long) cuts through several Pleistocene marine terraces, giving it a "fall line" type of topography. There has been some ditching for pasture improvement. Watershed aspect is southwest and most of the area has slopes within the 0-2 percent class. Soil types are those of W-2 and there is very little erosion. Ninety-six percent of the lands are in Class IV capability, 3 percent in Class III, and 1 percent in Class II. Surface drainage is generally sluggish; flow occurs mostly as intermittent ground water seepage.

This watershed generally represents partially improved rangeland along the Talbot and Penholoway marine terraces in the Southern Florida Flatwoods. The land is of low relief and is drained by gravity.

LAND USE

Land use in all three experimental watersheds has continued to change during the period of observation. Table 1 gives the land use estimated from SCS surveys.

TABLE 1.—*Land use*[1] *in Florida watersheds W-1, W-2, and W-3, specified years, 1954-1962*

Watershed and land use	1954		1956		1959		1960		1962	
	Acreage	Percentage	Acreage	Percentage	Acreage	Percentage	Acreage	Percentage	Acreage	Percentage
W - 1										
Citrus	10,250	21	12,000	24	17,000	34	19,000	38	20,000	40
Improved pasture	3,500	7	4,500	9	5,000	10	9,000	18	15,000	30
Range & forest	31,165	62	28,415	57	22,915	46	16,915	34	9,915	20
Misc.	5,000	10	5,000	10	5,000	10	5,000	10	5,000	10
W - 2										
Improved pasture	–	–	–	–	15,000	24	16,500	26	19,500	31
Unimproved pasture	–	–	–	–	28,000	44	26,600	42	24,000	38
Range & forest	–	–	–	–	11,000	17	10,500	17	9,168	14
Misc.	–	–	–	–	9,168	15	9,568	15	9,500	15
Citrus	–	–	–	–	0	0	0	0	1,000	2
W - 2										
Improved pasture	–	–	–	–	5,000	50	5,000	50	5,000	50
Unimproved pasture	–	–	–	–	1,500	15	1,700	17	1,800	18
Range & forest	–	–	–	–	2,000	20	1,800	18	1,700	17
Misc.	–	–	–	–	1,548	15	1,548	15	1,548	15

[1] Approximate acreage and percentage of land in watershed.

CLIMATE

The climate of the experimental watersheds is subtropical. Summers are long, warm, and humid with frequent showers which prevent temperatures from becoming extremely high. Winters are short and mild with little rainfall. Cold spells with frosts in the low-lying areas can be expected only a few times during the year.

All of the watersheds are within the area designated South and Central Division (Florida) by the U.S. Weather Bureau (USWB). The average annual temperature for south-central Florida is 72.7° F. Maximum temperatures during the summer months average 90° along the coast (W-1) and slightly above 90° in the interior (W-2, W-3). Minimum temperatures average 65°, but are slightly higher along the coast than inland.

Average annual rainfall for watershed W-1 is 52.46 inches as determined from a 62-year record at nearby Fort Pierce, Fla. Excess rainfall usually occurs from June through October with deficient rainfall in November, December, January, and February. Although the major portion of annual rainfall is received during the summer, high-intensity storms occur throughout the year.

Average annual rainfall for watersheds W-2 and W-3 is 47.96 inches, based on a 44-year record at Hurricane Gate 6 on the northeast levee of Lake Okeechobee. These two inland watersheds have heaviest rainfall in early summer, whereas the coastal watershed, W-1, has heaviest rainfall in early fall.

The south-central Florida area has periods of drought, although average annual rainfall is high. Years when rainfall is deficient are common and appear to occur in sequence. Also, periods of drought are not necessarily restricted to the winter months.

March and April are the windiest months and prevailing winds are southeast and east. Because most winds have passed over water surfaces, hot, drying winds are infrequent. High-velocity winds of short duration are associated with thunderstorms in summer and with cold fronts during other seasons. Tornadoes occur all year but are most frequent in spring and occasionally accompany tropical storms. Tropical hurricanes are the principal source of high winds and are usually accompanied by excessive rainfall.

SOIL TYPES AND CHARACTERISTICS

Table 2 gives the percentage of area in each watershed occupied by the various soil types; the depth, structure, and permeability of the topsoil, subsoil, and substratum; and the internal drainage of each soil profile.

The principal soils of Florida Watershed W-1 are Leon-Immokalee fine sand, Felda-Manatee loamy fine sand, and Pompano fine sand. Those of Florida W-2 and W-3 are predominantly Leon-Immokalee fine sand.

TABLE 2.–*Characteristics of soils of Florida Watersheds W-1, W-2, and W-3*

Soil type	Percentage of watershed area			Topsoil			Subsoil		Substratum		Internal drainage
	W1	W2	W3	Av. depth	Structure	Permeability	Structure	Permeability	Av. depth to substratum	Permeability	
				Inches					*Inches*		
Leon-Immokalee fine sand	50	65	77	4	Structureless fine grain sand	Rapid	Structureless (hardpan)	Moderate	36	Rapid	Medium
Plummer fine sand	0	8	8	4	Structureless fine grain sand	Rapid	Structureless fine grain sand	Rapid	40	Slow	Slow
Felda-Manatee loamy fine sand	26	6	0	8	Weak fine granular	Moderate	Weak, fine granular (massive when wet)	Slow	30	Slow	Slow
Sunniland-Bradenton fine sand	2	4	0	4	Structureless fine grain sand	Rapid	Weak, subangular blocky	Moderate	36-84	Slow	Medium
Pompano-Charlotte fine sand	0	3	5	2	Structureless fine grain sand	Rapid	Structureless fine grain sand	Rapid	48	Slow	Slow
Pompano fine sand	16	0	0	2	Structureless fine grain sand	Rapid	Structureless fine grain sand	Rapid	48	Slow	Slow
Rutlege fine sand	0	3	4	8	Structureless fine grain sand	Rapid	Structureless fine grain sand	Rapid	45	Slow	Slow
St. Lucie-Pomello fine sand	1	2	1	4	Structureless fine grain sand	Very rapid	Structureless fine grain sand	Very rapid	60	Very rapid	Very rapid
Fresh water swamp & marsh	0	3	2	3	Structureless fine grain sand	Rapid	Structureless fine grain sand	Rapid	40	Slow	Slow
Everglades peat	0	2	0	12	Fibrous	Rapid	Structureless fine grain sand	Rapid	48	Slow	Slow
Adamsville fine sand	5	2	2	4	Structureless fine grain sand	Rapid	Structureless fine grain sand	Rapid	48	Moderate	Medium
Delray fine sand	0	1	1	12	Structureless fine grain sand	Rapid	Structureless fine grain sand	Rapid	48	Slow	Slow
Parkwood fine sand	0	1	0	4	Structureless fine grain sand	Rapid	Structureless fine grain sand	Rapid	30	Slow	Slow

[4] Data based on surveys made by the Soil Conservation Service in Okeechobee and Indian River Counties, Fla.

GEOLOGY

Florida W-1

Pleistocene (Pamlico) and Recent sediments, which consist chiefly of gray to brown medium-grained quart zitic sand, cover the major portion of the watershed (8).[5] The shallow Pleistocene sand and shall beds of the Pamlico, Anastasia, and Fort Thompson Formations constitute a fairly permeable upper aquifer that contains nonartesian ground water. Locally, however, fine-grained sand or clay lenses can cause artesian conditions.

Most irrigation water is obtained from deep wells that penetrate the Floridian aquifer approximately 350 feet below the surface. The aquifer is made up of the following formations in ascending order: (1) Avon Park and Lake City Limestone (Middle Eocene); (2) Ocala Limestone (Upper Eocene); (3) Suwannee Limestone (Oligocene); (4) Tampa Limestone, and (5) permeable portions of the bottom of the Hawthorne Formation that are in hydrologic contact with the rest of the aquifer (Miocene). A thick bed of impermeable sediments lies over the Floridian aquifer, forming the greater portion of the Hawthorne Formation. Little, if any, recharge to the lower aquifer appears to occur in the vicinity of the watershed.

Florida W-2 and W-3

Undifferentiated marine terrace sands of Pleistocene age are found as surface deposits (7). Generally, the sands are white to gray in the upper part, and grade to tan, orange, and red at depth. They are the subrounded to sharp, nonfrosted detrital sediments characteristic of marine deposits. In the field it is impossible to distinguish between these terrace sands except by their altitudes. Since the upper subwatershed W-3 is part of this area, it is discussed as a part of the whole 98.7-square mile watershed.

The strand line of the Penholoway Terrace is about 68 feet mean sea level (m.s.l.) and that of the Talbot is about 50 feet m.s.l. The Penholoway Terrace, which covers approximately 40 percent of the area, lies in the northeastern part of the watershed. It forms a broad, flat, little-dissected plain that slopes gently to the south where it is broken by the wave-cut scarf of the lower Talbot surface. Approximately 15 percent of the watershed consists of the relatively steeply sloping scarf area between the Penholoway and Talbot plateaus.

The Talbot Terrace occupies the remaining 45 percent of the watershed area. It is remarkably flat; drainage is sluggish; and sloughs, shallow ponds, and swamps are abundant. The outer limit of the Talbot Terrace is generally ill-defined by the 22-foot strand line of the old Pamlico sea along the lower section of Taylor Creek.

Upper Taylor Creek basin is underlain by the Floridian aquifer, which is essentially of the same composition as that described for W-1. The impermeable Hawthorne Formation, which apparently underlies the entire peninsula except the Ocala uplift, forms an aquiclude that seals off the artesian water in the Floridian aquifer. The Hawthorne also serves as a "floor" for generally unconfined ground water in the Caloosahatchee Formation (Pliocene) and in the mantle of sandy Pleistocene sediments.

The piezometric head of water in the Floridian aquifer beneath watersheds W-2 and W-3 is approximately 50 feet, m.s.l. Since most of the land lies above this elevation, flowing artesian wells can be obtained only in the lower lying valleys along streams in the southern part of the watershed. A few such wells are used for irrigation. Limited supplies of ground water for local use can be obtained from the more permeable strata of the Caloosahatchee or the Pleistocene sediments. The ground water level in the watershed is generally within 1.5 to 3 feet of the surface and shows marked response to local weather conditions.

FLUVIAL GEOMORPHOLOGY[6]

Physiographic Setting

Taylor Creek (W-2) is located in the East Florida Flatwoods physiographic subprovince (2). Drainage is to the south into Lake Okeechobee, then into the Gulf of Mexico and the Atlantic through numerous rivers and dredged channels. Watershed W-1 is not a natural drainage basin but a diked area with manmade boundaries. As such, it is not a proper subject for geomorphic analysis.

Geomorphic Interpretations

Data were taken from the U.S. Geological Survey (USGS) 7½-minute quadrangle sheets. This limits the extent of the investigations, since not all stream channels appear on the maps, and the 5-foot contour increments do not allow the resolution desired for detailed topographic definition. Assuming, however, that little better information can be obtained for any other area in this

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[5] Underscord numbers in parentheses refer to Literature Cited, p.

[6] Based on investigations by and personal correspondence of W. H. Allen, Jr., research geologist, USDA Hydrograph Laboratory, Beltsville, Md.

region, these maps suffice to describe basic geomorphic features.

To compute the drainage density of Taylor Creek, a method similar to that of Strahler (13) is used. First-order channels are unbranched tributaries at the head of the drainage net. Second-order channels are formed when two first-order channels converge, and so on. First-order channels can enter any higher order channel along its length as long as it is unbranched. The highest order channel is, therefore, the one through which the water leaves the watershed. Table 3 gives the drainage net characteristics of Taylor Creek as computed from the 7½-minute quadrangle sheets.

Drainage density (D_d) is the total length of the channels in miles divided by the area in square miles (13.) In Upper Taylor Creek (W-3) the 0.72 value is low, perhaps because the upper watershed is developed almost entirely on the Penholoway Terrace. According to geomorphic theory, the low density of the channel network indicates that little of the runoff occurs as overland flow. When the entire watershed (W-2) is considered, the D_d is higher, indicating that infiltration capacity is lower on the Talbot Terrace than it is in the upper portions of the catchment area. However, this does not appear to be the case based on the hydrograph analysis discussed in the section *Types of Flow*. The reasons for this apparent paradox are not known. Assuming that the formation of drainageways in the Land Resource Area is associated with ground water solution processes, as in formation of the karstlike sinks, then the greater drainage density of channels in watershed W-2, which has less surface runoff, is understandable.

The bifurcation ration (R_b) is quite low on both the upper and lower portions of the watershed. This parameter, which is a measure of the ratio between successive stream order segments (5), indicates that the length of the watershed is not disproportionately greater than the width. Therefore, few first-order channels enter the high-order channels, a phenomenon explained by the low D_d. However, when the entire watershed is considered, the R_b value is about 50 percent greater. Thus, R_b is related to the size of the watershed.

Stream frequency(F_s), which is a measure of the total number of stream order segments over the area in square miles, is also low (13). Probably few other areas of the State or Nation, except the Coastal Terraces, exhibit such low stream frequencies. The stream length ratio (R_L) is defined as the ratio of mean length of segments of one order to mean length of segments of the next lower order (6).

TABLE 3.–*Stream geomorphic characteristics of Taylor Creek watersheds*

Watershed designation	Area (sq. miles)	Channel order No.[1]	No. of channel segments (ΣN)	Bifurcation ratio (R_b)	Length of channels (ΣL) (miles)	(av.L)	Length ratio (R_L)	Drainage density (D_d)	Stream frequent (F_s)	Length of overland flow (L_q)[2]
		1	5		6.43	1.29				
				2.50			1.43			
Uper Taylor Creek (W-3)	15.7	2	2		3.71	1.85		0.72	0.51	0.69
				2.00			0.66			
		3	1		1.22	1.22				
			8	R_b = 2.25	11.36		R_L=1.00			
		1	85		61.9	0.72				
				4.25			1.82			
		2	20		26.3	1.31				
				2.22			1.33			
Taylor Creek (W-2)	98.7	3	9		15.7	1.74		1.20	1.19	0.45
				4.50			3.48			
		4	2		12.1	6.05				
				2.00			0.33			
		5	1		2.0	2.00				
			117	$\bar{R}_b$= 3.24	118.0		$\bar{R}_L$=1.74			

[1] As defined by Strahler
[2] L_q = ½ av. dist. between drainageways

The hypsometric curves for Upper and Lower Taylor Creek are shown in figures 4 and 5. In these two figures, relative height (h/H) is plotted against relative area (a/A) where:

y = the ratio of height of a given contour increment (h) to total basin relief (H), and

x = the ratio of horizontal cross-sectional area (a) to the entire basin area (A),

as defined by Langbein (6).

The curve in figure 4 shows clearly that portion of W-3 which lies on the upper (Penholoway) terrace. The flat upper part, which represents 78 percent of the total area, is entirely on the Penholoway surface. The remaining portion of the curve (22 percent) represents the area of relatively strong relief—the break between the two terrace levels—and a small portion of the Talbot Terrace just upstream from the gaging site in W-3.

Figure 5 gives a composite picture of watershed W-2. Both terraces are prominently represented, and the curve shows the percentage of area that each occupies on the watershed.

Ground water levels have been measured at seven wells randomly located on the watershed. By taking the mean annual depth of the water table below the surface

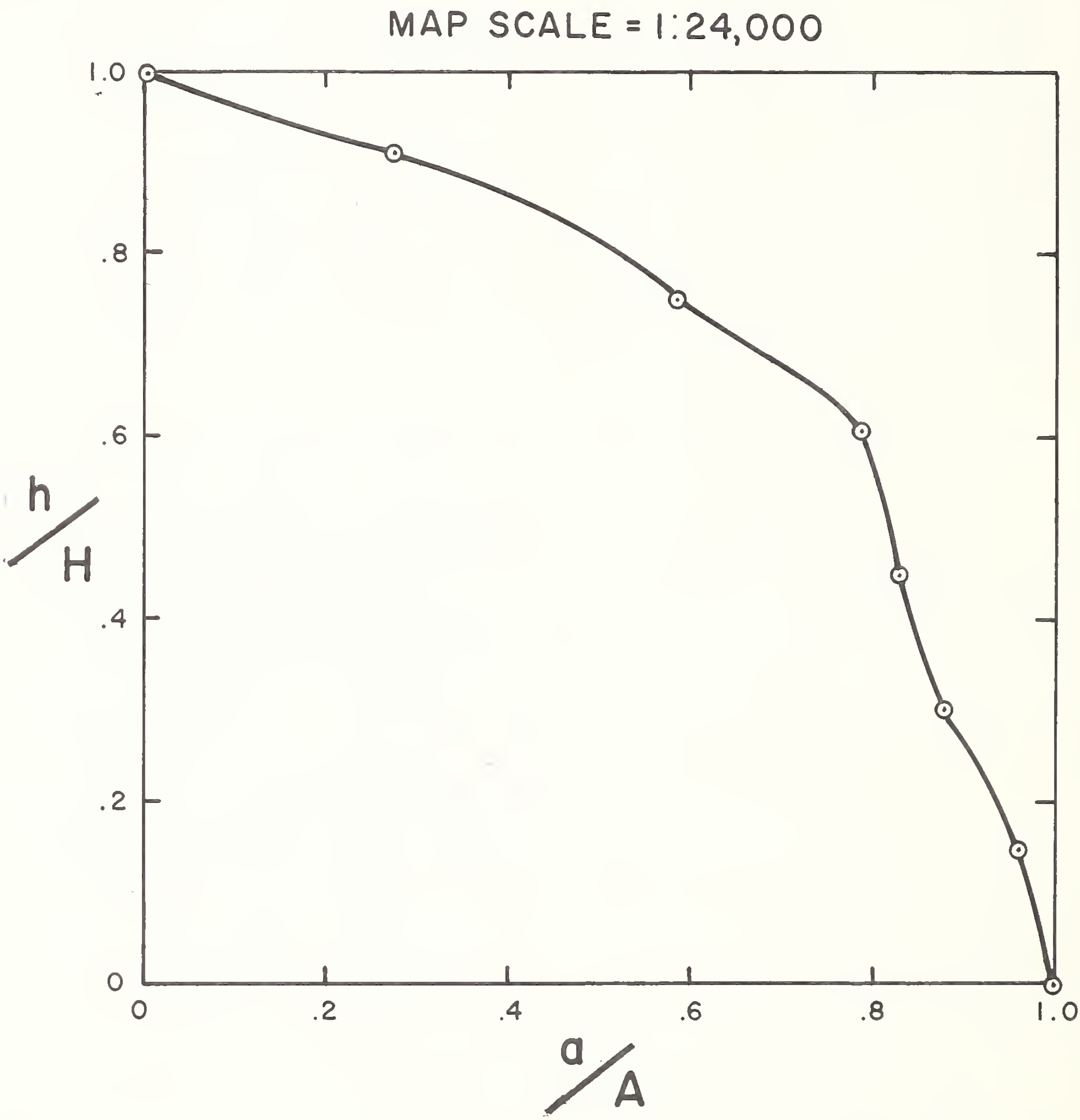


Figure 4.—Hypsometric curve, watershed W-3. Area ratios (a/A) and relative elevations (h/H) were derived from topographic maps with a 1:24,000 scale and 5-foot contour intervals. This watershed lies on the Penholoway Pleistocene marine terrace.

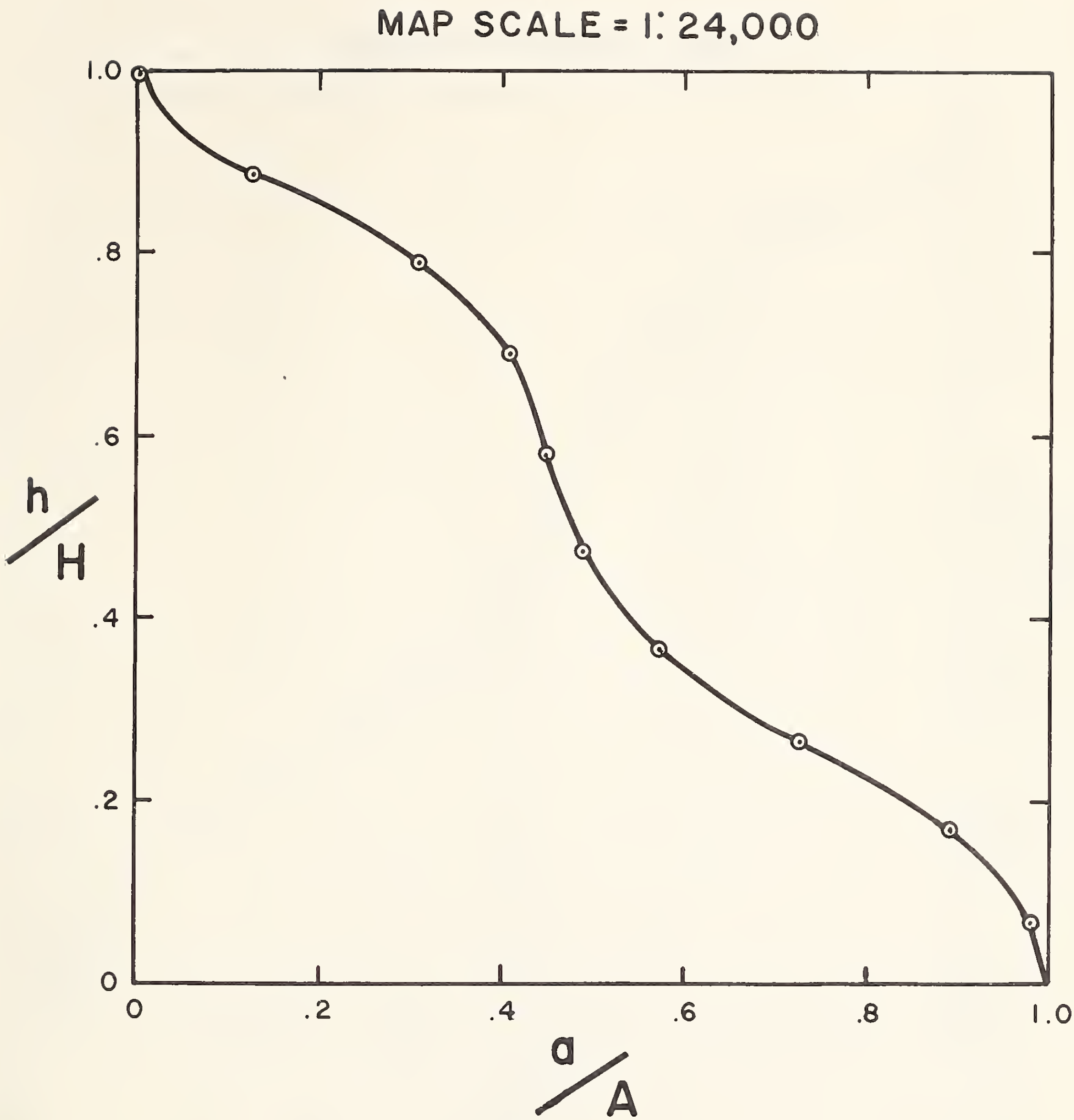


Figure 5.–Hypsometric curve, watershed W-2 (W-3 included). Area ratios (a/A) and relative elevations (h/H) were derived from topographic maps with a 1:24,000 scale and 5-foot contour intervals. The land area of this watershed is almost equally divided between the Penholoway and Talbot Pleistocene marine terraces. The relatively steep scarp between terraces is apparent.

and extrapolating the contour map for the top of this surface, a hypsometric curve was drawn. The results, shown in figure 6, are almost congruent to those in figure 5. Therefore, there is no significant difference between the ground surface and the surface of the water table, which lies between 1 and 3 feet below ground level.

Longitudinal Profile of the Main Stem

Although the longitudinal profile of the main channel does not show the two terraces as well as the hypsometric plotting does, it indicates the areas where channel stabilization would be most needed on this watershed in its natural state. Since the Talbot Terrace was abandoned by the sea, the channel has adjusted and degraded itself upstream to compensate for the 30-foot drop between the two terraces. Through natural processes, the channel should tend to smooth out completely. Because this has not yet happened, it can be expected to be the major geologic change in the future. A drop structure proposed for the area near the outlet of W-3 would be located in a reach of the channel where the gradient is greater than at any other location along the main stem (fig. 7).

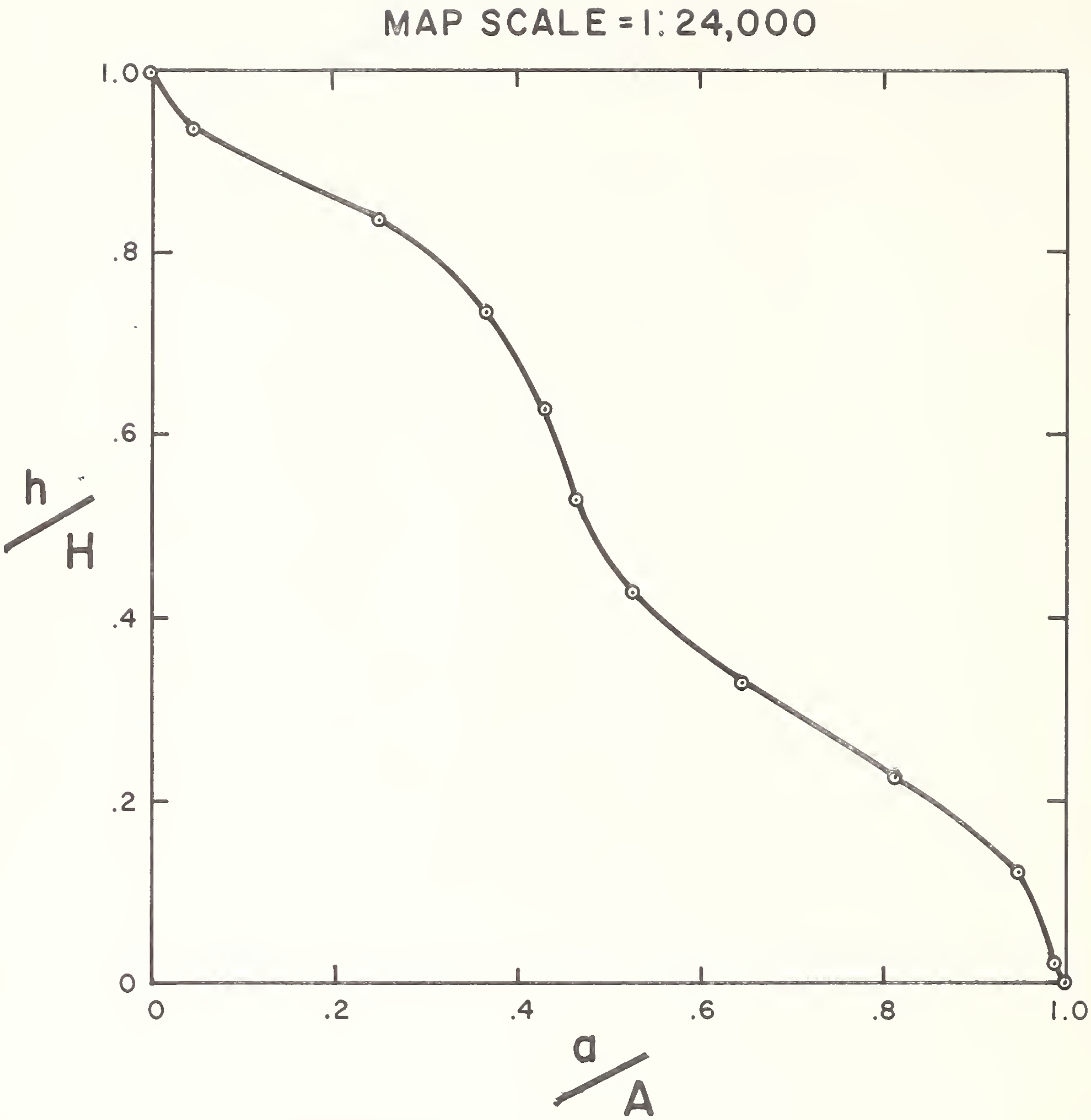


Figure 6.—Water table hypsometric curve, watershed W-2 (W-3 area included). A comparison of this curve with the curve shown in figure 5 shows no significant difference between land surface and water table surface depths.

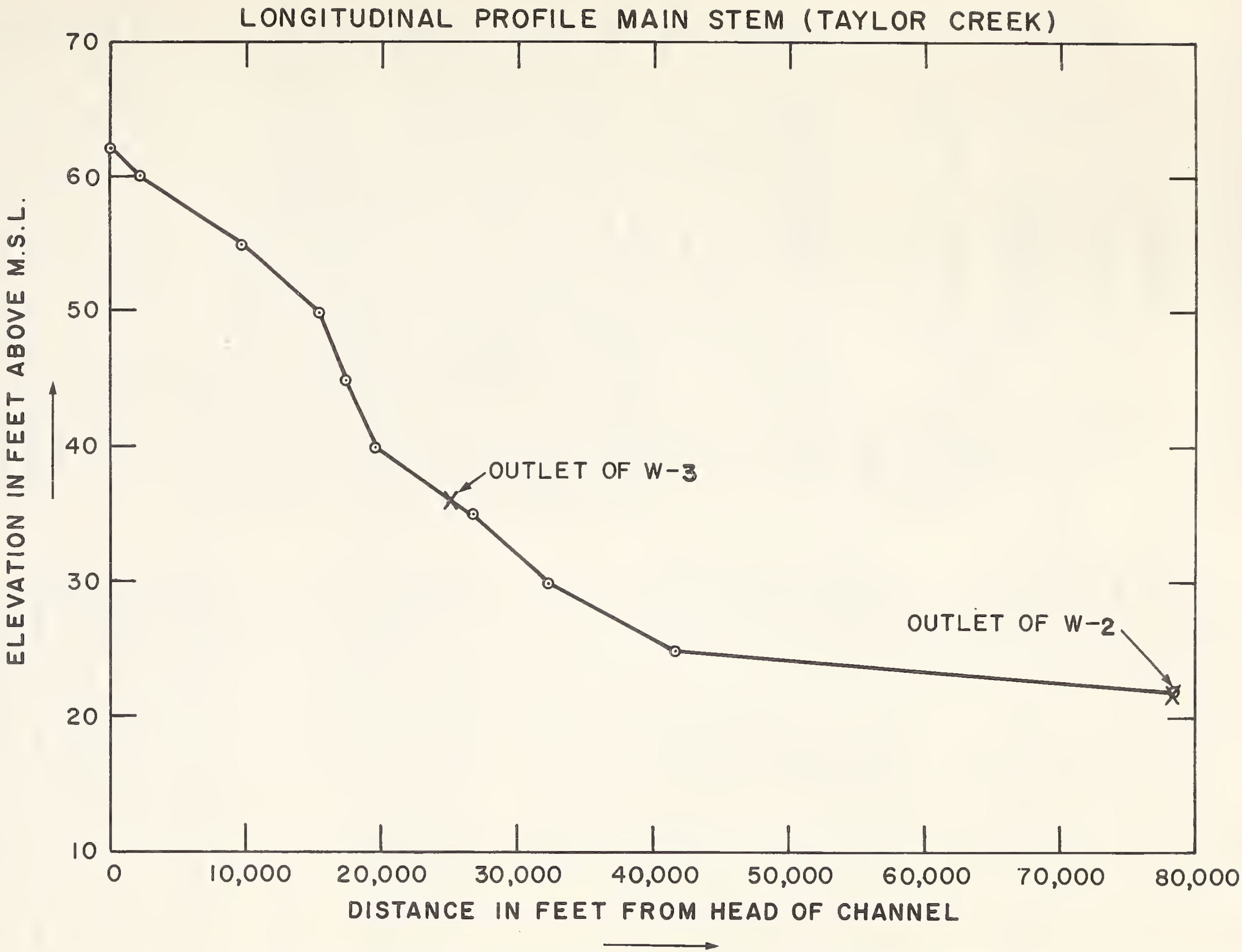


Figure 7.–Longitudinal profile, main stem–Taylor Creek. Proposed drop structures (1962) for water level control are at indicated outlets.

PRECIPITATION

Florida W-1

Rainfall is measured by five Friez 9-inch-capacity weighing recorders with 192-hour gearing. The network is augmented by a standard 8-inch USWB nonrecording gage maintained by the Federal Aviation Agency, in conjunction with a recording gage. Gage coverage averages 15.6 square miles per gage. Watershed rainfall is calculated from the gages by Thiessen weighting using the percentages: 14, 16, 26, 19, and 25 for each gage as numbered, respectively, in figure 2.

Florida W-2, W-3

Rainfall is measured by seven Friez 9-inch-capacity weighing recorders with 192-hour gearing. At one of these gage sites, an 8-inch standard USWB nonrecording rain gage is maintained in conjunction with a standard USWB evaporation pan. Two of the seven gages are Thiessen weighted with the percentages 43 and 57 for gages 1 and 2 in figure 2, on watershed W-3. For W-2 the Thiessen percentages are 9, 13, 10, 15, 12, 18, and 23, respectively, as numbered in figure 3. Gage coverage averages 14.1 square miles per gage for W-2, and 15.7 square miles for W-3.

GROUND WATER

Florida W-1

There are no wells in this watershed to measure phreatic, or unconfined, ground water levels. However, two Bristol-type recorders, mounted on unused deep wells, monitor artesian pressure continuously in the Floridan aquifer. Records have been maintained since 1951.

Florida W-2, W-3

Ground water stage recorders were installed at the seven rain gage sites in 1959. These are Stevens Type F water level recorders, with 192-hour gearing. All well and rain gage site numbers correspond at each site as indicated in figure 3. The recorders are serviced each week when the rain gage charts are changed. In addition to these recording wells, two well lines, each consisting of six 1½-inch-I.D. ground water wells, have been established perpendicular to the stream in both the upper and lower reaches of the main watercourse. These wells are logarithmically spaced within 2,000 feet of the stream and are observed weekly. An additional Stevens Type F recorder was installed on each of these lines where average ground water levels occur.

RUNOFF

Runoff from the experimental watersheds is measured by the USGS by cooperative agreement. Daily runoff totals are furnished annually to ARS. Runoff hydrographs for selected storms are computed from USGS stage records and rating curves, and are supplied to ARS on request.

Descriptions and locations of stream gaging stations are:

Florida W-1

This watershed is actually a composite of three individual watersheds connected by equalizing canals and drainageways. Runoff from the total drainage area is measured through three outfall canals: Main, North Relief, and South Relief. Exact drainage area for each outfall canal is indeterminate, depending on rainfall distribution over the total area. Locations of stream gaging stations are shown in figure 2.

Main Canal.—Rated cross section with stage recorder. Latitude 27° 38' 54", Longitude 80° 24' 10", in SE¼ Sec. 35, T. 32S, R. 39E. 700 ft. upstream from U.S. Highway 1, and 0.6 mile N.W. of Vero Beach, Fla. Records are good to fair as qualified by the USGS.

North Relief Canal.—Rated cross section with stage recorder. Latitude 27° 41' 32", Longitude 80° 25' 00", in SE¼ Sec. 15, T. 32S, R. 39E. 600 ft. upstream from bridge on U.S. Highway 1, and 3.9 miles N. of Vero Beach, Fla. Records are fair to poor.

South Relief Canal.—Rated cross section with stage recorder. Latitude 27° 36' 11", Longitude 80° 23' 24", in SW¼ Sec. 13, T. 33S, R. 39E. 1,000 ft. upstream from bridge on State Highway 605 and 2.5 miles S. of Vero Beach, Fla. Records are fair.

Florida W-2

This watershed is on the mainstream of Taylor Creek and its drainage area is 98.7 square miles. Rated cross section with stage recorder. Latitude 27° 17' 03", Longitude 80° 49' 20", in NW¼ Sec. 3, T. 37S, R. 35E. On the downstream side of County bridge on Cemetery Road, 2.8 miles N. of Okeechobee City, Fla. and 7.6 miles upstream from Lake Okeechobee. Records are fair

to poor. The location of the stream gaging site is shown in figure 3. This gage is located on the Township line. The two gages shown approximately 1 mile upstream on the mainstream and tributary are proposed gages (1962).

Florida W-3

This watershed is on the mainstream of Taylor Creek and its drainage area is 15.7 square miles. It is a rated structure (broad-crested wooden weir) combined with rated cross section. Latitude 27° 23' 36", Longitude 80° 53' 42", SE¼ Sec. 26, T. 35S, R. 34E. About 500 ft. downstream from the road bridge on State Highway 68, and 8.5 miles E. of Bassinger Community, Fla. Records are good to fair. The location of stream gaging site is shown in figure 3.

HYDROLOGY

PRECIPITATION

Precipitation on the Florida experimental watersheds occurs almost exclusively as rainfall. Rainfall distribution is examined in both time and space. Time distributions are considered for both monthly periods and for individual storms. Spatial distribution has been found to even out for periods of a month or longer. For individual storms, spatial distribution is characterized in this report by depth-area relationships.

Monthly Rainfall Distribution

Average monthly rainfall for watersheds W-1, W-2, and W-3 is shown in figure 8. These monthly averages were computed from 7 years of record (1956-62). Table 4 compares the mean monthly and annual rainfall determined from the long-term records of nearby gages with the 7-year monthly and annual averages for coastal watershed W-1 and inland watershed W-2.

A statistical comparison of the average annual rainfall on W-1 for the 7-year period (1956-62) and the average annual rainfall at Fort Pierce for 62 years (1901-62) showed no significant difference. In contrast, a comparison of the 7-year average annual rainfall on W-2 and the 44-year average annual rainfall at Okeechobee Hurricane Gate 6 showed a highly significant difference.

A comparison between the 7-year (1956-62) and the 44-year average annual rainfall at Okeechobee Hurricane Gate 6 showed that the difference in these amounts of annual rainfall was also highly significant, with the 7-year average being greater. We therefore concluded that during the 7-year period (1956-62) rainfall was above the long-term average in the vicinity of W-2.

Storm Rainfall

To provide information on storm rainfall characteristics in the experimental watershed areas, major high-intensity, high-volume storms that occurred over watersheds W-1 and W-2 were analyzed. Depth-area duration relationships were determined and time distribution patterns defined.

For each watershed, 15 storms lasting 24 hours or less were selected from rainfall records[7] on the basis of greatest 24-hour point rainfall. The selected storms were grouped into two classes by duration—storms longer than 12 hours and storms shorter than 12 hours.

Storm time distribution patterns.—Time distribution patterns were established for both the long- and short-duration storms. These distribution patterns are shown in figure 9 as percentage of total storm duration. The curves represent the usual distribution patterns of the events studied, although individual storm distributions varied from these median curves.

When synthesizing a design storm, engineers of the SCS select one of four standard storm distribution curves.[8] Generally, one or more of these curves is considered applicable to the rainfall time distribution of each region.

A comparison of the rainfall time distribution curves for central and southern Florida (fig. 9), with the four storm distribution curves used by SCS, shows that the distribution curve for storms of long duration in Florida approximates the SCS "C" distribution curve. The curve for storms of short duration in Florida approximates the SCS "B" distribution curve.

The storm-time distribution curves shown in figure 9 should approximate storm patterns for most of central and southern Florida. They are useful guides for selecting storm-time patterns on which to base design of drainage and flood control structures for the agricultural areas of this region.

Depth-area relationships.—Depth-area relationships were determined for the long-and short-duration storms

[7] Periods of rainfall records reviewed were April 1951-September 1964 for W-1, and June 1955-September 1964 for W-2.

[8] See figure 3.21-9, Engineering Handbook-Hydrology, Section 4, Supplement A, SCS, USDA.

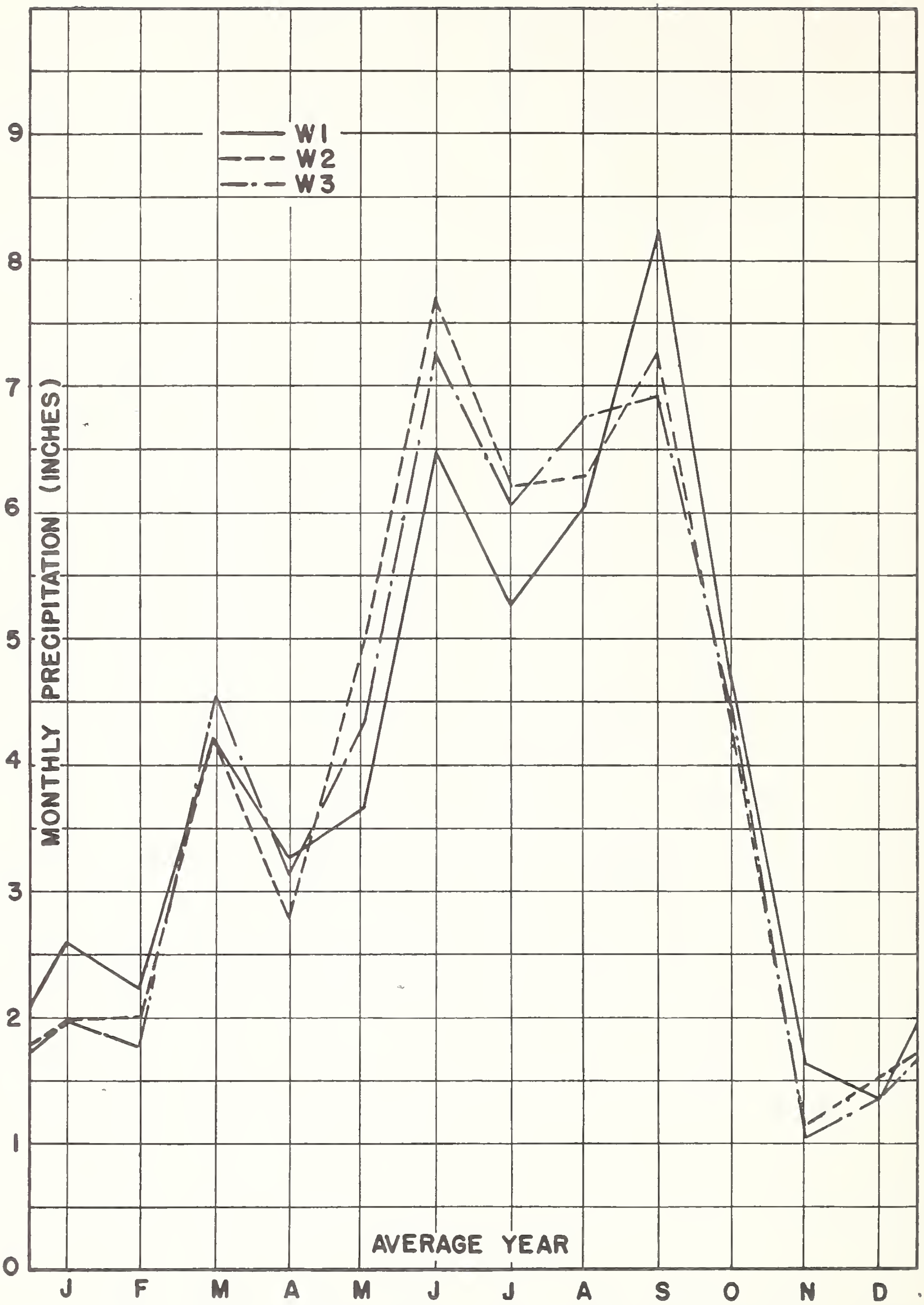


Fig. 8

Figure 8.—A comparison of average monthly rainfall on Florida watersheds W-1, W-2, and W-3. Monthly volumes are connected by lines.

TABLE 4.–*Long-term monthly precipitation data and short-term (7 years) averages, for coastal watershed W-1 and inland watershed W-2*

Month	Watershed W-1		Watershed W-2	
	62-yr. av.[1]	7-yr. av.	44-yr. av.[2]	7-yr. av.
	Inches	*Inches*	*Inches*	*Inches*
January	2.35	2.64	1.61	1.98
February	2.35	2.29	1.72	2.00
March	3.04	4.33	2.79	4.27
April	3.40	3.43	3.40	2.78
May	4.28	3.78	3.95	4.99
June	5.87	6.43	7.10	7.69
July	5.52	5.58	6.06	6.37
August	5.67	5.79	6.08	6.43
September	7.87	9.02	7.18	7.74
October	7.34	4.95	4.92	4.49
November	2.76	1.86	1.70	1.29
December	2.01	1.30	1.45	1.40
Annual	52.46	51.40	47.96	51.43

[1] As measured by gage at Fort Pierce, Fla.
[2] As measured by gage at Okeechobee Hurricane Gate 6.

of both watersheds. Isohyetal maps were constructed for each storm using total rainfall amounts. From the isohyetal map of each event, average rainfall was determined for areas between isohyetals. Then, beginning with the area having greatest rainfall, average rainfall was determined for increasingly larger areas by including rainfall on adjacent areas and weighing each rainfall amount according to the size of the area.

Rainfall for each of the accumulative areas was expressed as percentage of maximum point rainfall and plotted against area. These depth-area relationships were linear when plotted on semilog graph paper.

A simple linear correlation was applied to the depth-area data. The following regression equations were obtained from the W-1 data:

Log P' = 2.0012 - 0.001161 M for storms longer than 12 hours;

Log P' = 1.9969 - 0.002773 M for storms shorter than 12 hours;

(P' is rainfall depth expressed as percentage of maximum point rainfall and M is area in square miles.) The Florida W-2 data produced the following regression equations:

Log P' = 2.0075 - 0.000896 M for storms longer than 12 hours;

Log P' = 2.0018 - 0.002952 M for storms shorter than 12 hours.

Correlation coefficients for the coastal watershed, W-1, were 0.826 for the long-duration storms and 0.865 for the short-duration storms. For the inland watershed, W-2, correlation coefficients were 0.881 and 0.861 for the long- and short-duration storms, respectively. Enveloping lines were established two standard errors above and below the regression lines. Standard errors of rainfall depth (in logarithmic terms of percent maximum point rainfall) for the W-1 depth-area were 0.0208 for long-duration storms, and 0.0422 for the short-duration storms. Standard errors for W-2 depth-area data were 0.0168, and 0.0606 for the long- and short-duration storms, respectively. Figure 10 shows the regression and enveloping lines.

Depth-area relationships shown in figure 10 for long- and short-duration storms on W-1 and W-2 provide information for design purposes. Rains lasting less than 12 hours exhibit similar depth-area relationships for both rain gage networks. Apparently, depth-area relationships for these shorter storms are similar for coastal and inland areas. A greater slope of the depth-area regression line for storms longer than 12 hours for W-1 than for W-2 indicates some difference in areal rainfall patterns between longer coastal and inland storms.

When designing facilities to handle storm rainfall, the regression lines or equations and enveloping lines given in figure 10 can be used to adjust probable point rainfall frequency values (provided by the USWB (4)) to areal rainfall values. Where it is necessary to derive areal rainfall from predicted point rainfall with reasonable accuracy, the enveloping lines are applicable. Average depth-area conditions, however, would be represented by the regression lines. Selection of the regression line, upper enveloping line, or some point in between as a basis for obtaining a rainfall adjustment factor would depend on conditions of each design situation and would usually be influenced by economic considerations.

EVAPOTRANSPIRATION

Various formulas have been devised for using meteorological data to compute evaporation and potential evapotranspiration. Stephens and Stewart (12) compared various formulas to find the one most appropriate for southern Florida. The evaluation was based on the correlation between computed water losses and measured evaporation from USWB evaporation pans, and potential evapotranspiration from St. Augustinegrass grown in evapotranspirometers at the Plantation Field Laboratory near Fort Lauderdale.

The Fractional Evaporation-Equivalent Method, using measured radiation R, seemed best suited for central and southern Florida. For practical use, monthly potential evapotranspiration can be estimated from the equation, $ET = (0.0082\overline{T}_a - 0.1900) \times R_s/1{,}500$, in which ET =

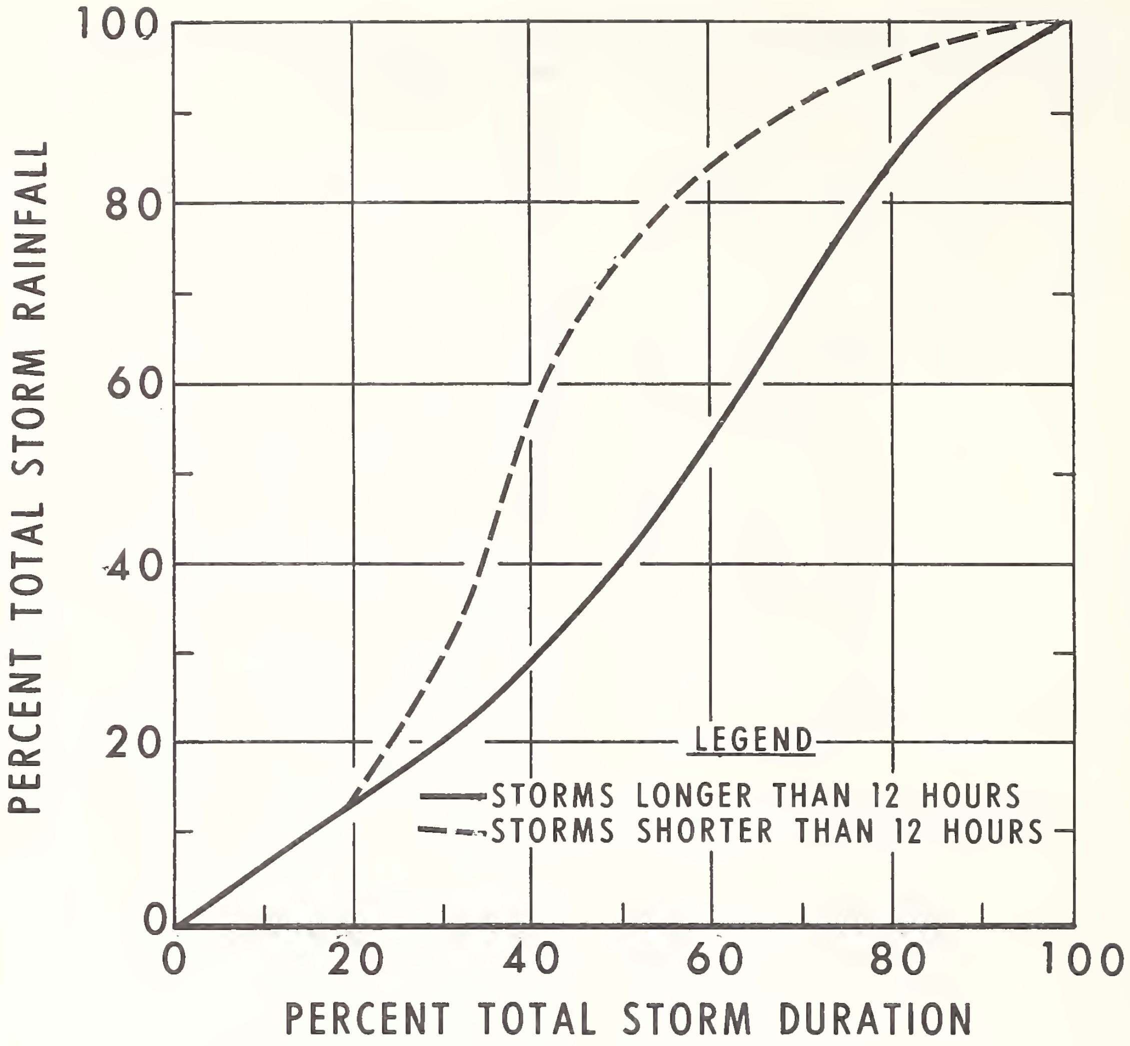


Figure 9.–Time distribution curves representing usual distribution (modal) patterns for high-intensity rainfall on watersheds W-1 and W-2.

potential evapotranspiration in inches per month for a complete vegetative cover where moisture supply is not a limiting factor and the oasis effect is negligible; $\overline{T}_a$ = the average monthly temperature in degrees Fahrenheit; and R_s = solar insolation in langleys (10).

Where R_s records are not available, satisfactory results can be obtained from the monthly langley distribution maps in the "National Summary" published by the USWB. Estimates of evaporation from open water can be derived from ET using appropriate coefficients.

Recent studies at Fort Lauderdale indicated a linear relationship between plant density or percentage of sod cover and evapotranspiration of Tifway bermudagrass grown on Arzel fine sand with the water table at 24 inches. This may be expressed as the function $Y = 0.56X + 44$, where X is the percentage of ground covered by grass, and Y is the percentage of potential evapotranspiration from full sod cover. Further studies of this relationship with a 36-inch water table are underway.

Weaver and Stephens (14) found that the standard USWB pan, as an integrator of climatic factors, appears to be a valuable index of crop water requirements in southern Florida when soil moisture is not a limiting factor. For St. Augustinegrass, the relationship between evapotranspiration (ET) and open pan evaporation (E) was expressed by the equation $ET = 0.766E - 0.011$, in which ET and E are expressed as inches of water per day.

From 1957 to 1959, the ratio of ET of St. Augustinegrass with a 24-inch water table to USWB pan evaporation was approximately 0.70. This varied from about 0.61 during the winter to 0.74 during the summer. Significant differences in evapotranspiration of sod crops grown on sandy soils with 12-, 24-, and 36-inch water

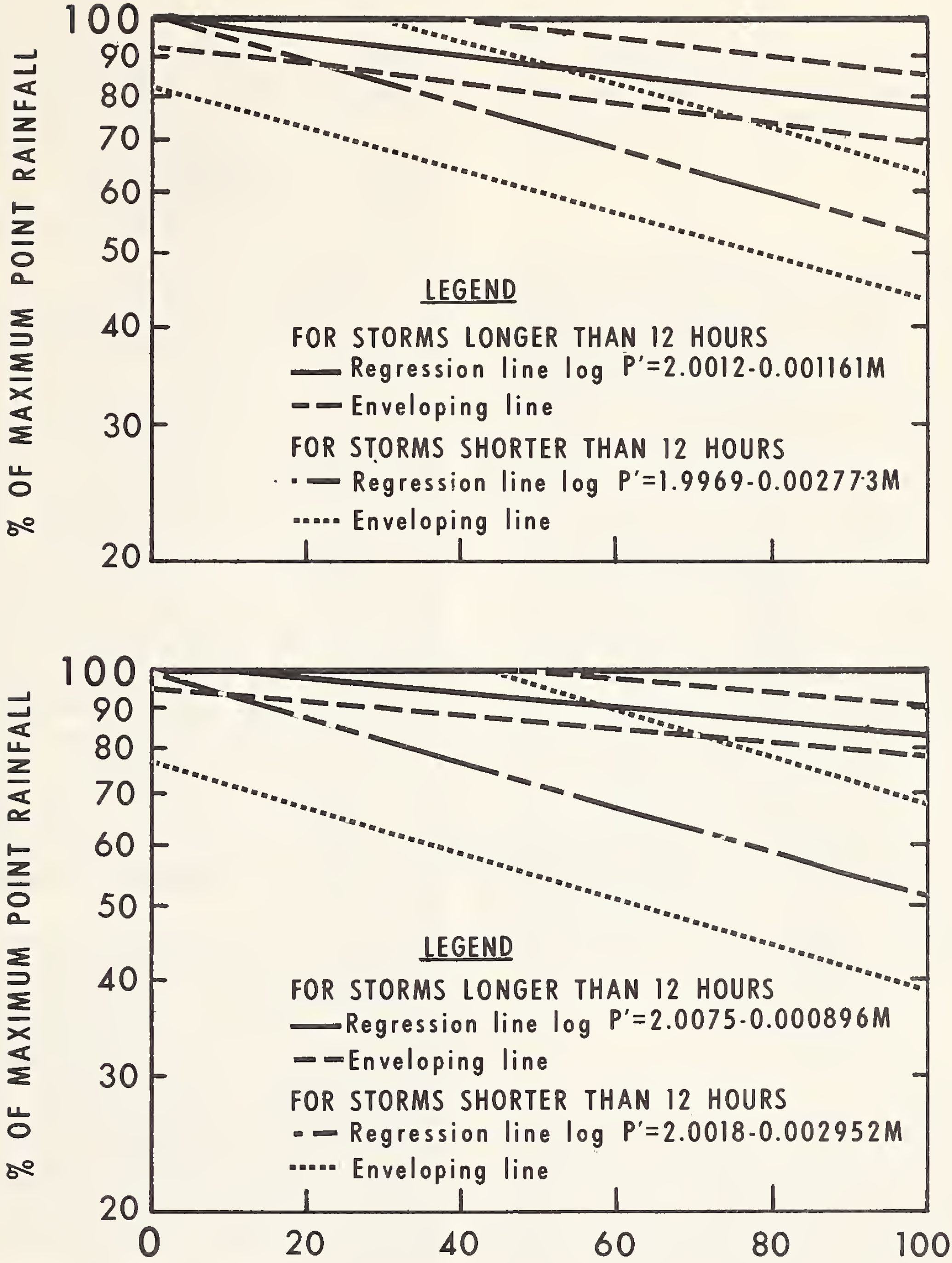


Figure 10.–Depth-area relationships of extreme rainfall events on Indian River Farms Drainage District (Fla. W-1) (above), and Taylor Creek Watershed (Fla. W-2) (below). Florida W-1 relationships are extrapolated from 78 to 100 square miles.

tables were found only during prolonged dry periods. Evapotranspiration with a 36-inch water table was about 88 percent of that with a 24-inch water table during such periods.

Evaporation

Water surfaces.—When installed and operated according to USWB specifications, the USWB class A pan is essentially a standardized calorimeter. Standard pans are generally used as the yardstick to which coefficients are applied for conversion to other evaporative processes. A pan coefficient of approximately 0.80 is applicable for estimating lake evaporation in southern Florida. For example, average annual evaporation at the Everglades Experiment Station for the period 1953-57 was 64.1 inches from a USWB pan compared with 51.9 inches from Lake Okeechobee, as computed from the water balance in USGS Water Supply Paper WS 1255 (8).

Soil surfaces.—Atmospheric conditions that affect evaporation from a free water surface also affect soil water evaporation. The physics of soil moisture movement is complex and depends on a number of environmental factors such as color, surface roughness, wetness, and soil properties. Penman (9) estimates that potential evaporation from bare soil approaches 90 percent of that from open water . At Fort Lauderdale, evaporation losses from fallow sandy soil in tanks with a water table maintained at a depth of 12 inches were about the same as lake evaporation; with a water table maintained at a 36-inch depth, evaporation from soil was approximately 20 percent of lake evaporation.

RUNOFF

Surface Water

The standard terms "overland flow", "interflow", and "base flow" do not necessarily describe the conditions that produce runoff. These flows are not clearly separated in the flatwoods watersheds. More descriptive terms would be rapid flow, intermedial flow, and slow flow. These terms refer to *rate of flow* rather than causes, and such terms have been used interchangeably in this report. *Total* flow is the amount of streamflow measured, by rate or volume, that passes through the USGS gaging sites.

Annual volumes.—Rapid flow, or overland flow, occurs infrequently on the watersheds, usually after the soils are saturated from previous rainfall. The high infiltration rates of the sandy soils limit surface runoff to the volume of rainfall in excess of soil storage capacity. On watersheds W-1 and W-2, rapid flows occurred only 2.5 percent of the time. These flows contributed an average of 9.3 percent and 6.9 percent to the total annual runoff for W-1 and W-2, respectively, for the period 1956-62. Rapid flows occurred 5.5 percent of the time on watershed W-3 and contributed 29 percent to its total annual volume.

Figure 11 shows the distribution of average monthly runoff for the three watersheds. Most rapid flow runoff occurs in September and October.

Contribution to peak flow volumes.—Discharge volumes for sustained periods of maximum annual runoff events and the percentage of these individual volumes attributable to rapid flow are shown in table 5. To estimate these percentages, the portion of runoff that occurred below the predetermined flow rate at which rapid flow began was extracted from the total runoff. Since the predetermined flow rates were established by analysis of recession limbs of hydrographs only, they are not necessarily accurate for periods preceding peak flows. However, the rising limb of the hydrograph is usually short compared with the recession limb, and major portions of storm runoff occur with receding flows. Therefore errors are not considered significant in terms of total rapid runoff. For watersheds W-1, W-2, and W-3 the lower limits of rapid runoff were 670 c.f.s., 1,100 c.f.s, and 65 c.f.s., respectively.

For most years, major runoff events had flow rates that exceeded the lower limits of rapid runoff for at least 48 hours. In each instance, all slow and intermedial flow was extracted from the total volume of runoff during the event.

In figure 12 the three watersheds are compared showing the ratio of rapid runoff to total storm runoff as a function of duration. Most peak flows for the small watershed (W-3) and the large well-drained watershed (W-1) occurred as rapid runoff. The percentages of peak runoff attributed to rapid runoff for W-1 and W-3 were more than twice that of W-2. In the large, poorly drained watershed (W-2), surface waters did not have ready access to drainage channels, so flooding was more persistent. The dense stands of cypress and heavy undergrowth in the lower portions of W-2 also impeded rapid flow.

Pond storage.—Reservoir action of ponds and sloughs moderates rapid runoff rates. Such action eventually contributes to ground water storage and recharge. This storage is a more important factor on watershed W-2 than on watersheds W-1 and W-3. Pond storage on W-2 accounts, in part, for the high threshold (1,100 c.f.s.) at which rapid flow rates begin and intermediate rates end.

The influence of pond storage becomes apparent when water tables measured within watersheds W-2 and W-3 reach an average depth of about 1.5 feet below ground surface. When water tables are closer to ground surface, there is little correlation between water tables

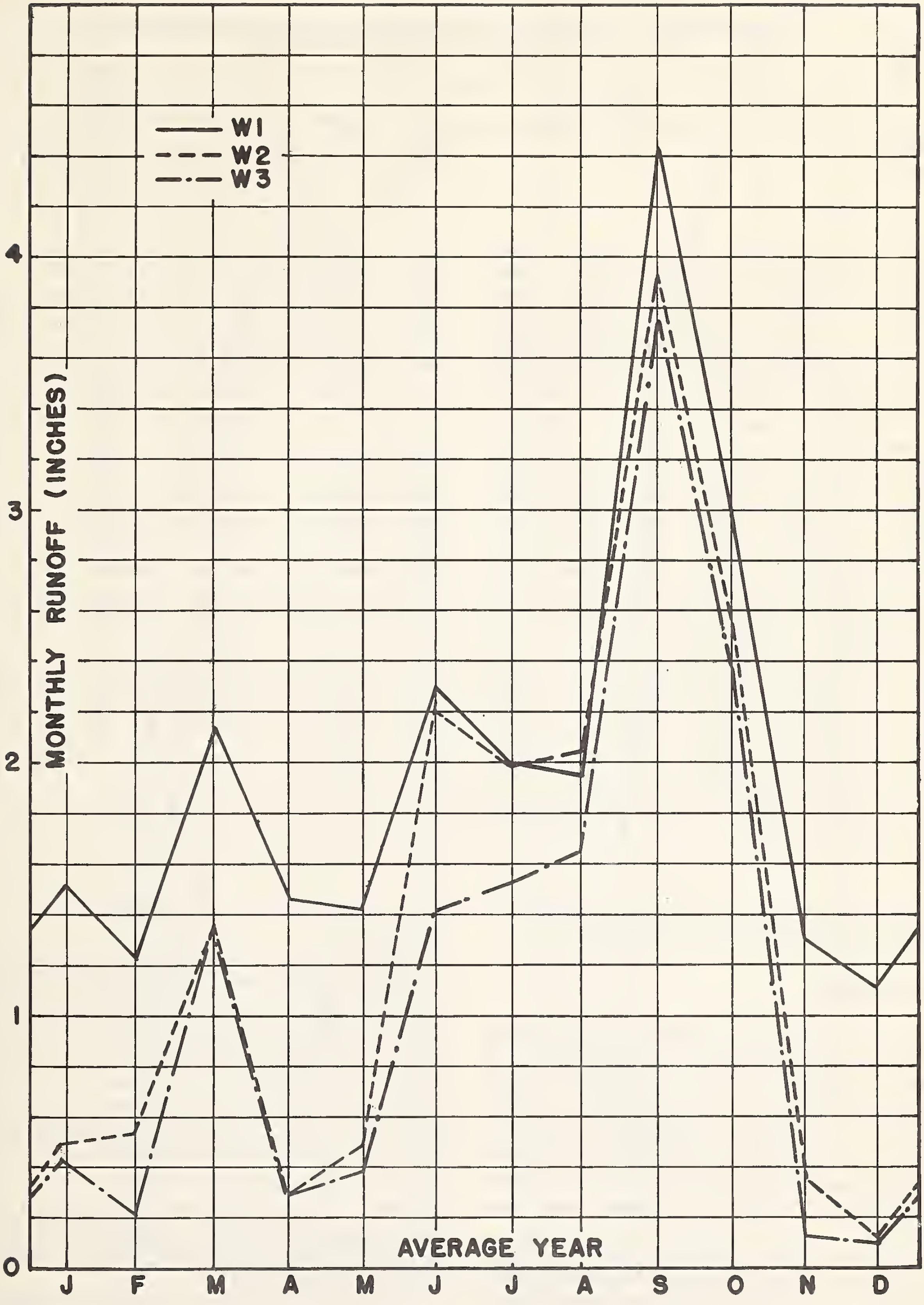


Figure 11.–A comparison of monthly runoff volumes for an average year during the period 1956-62 for Florida watersheds W-1, W-2, and W-3. Monthly volumes are connected by lines as indicated.

Fig. 11

TABLE 5.–*Maximum runoff for selected periods during each year and percentage of volume attributable to rapid runoff, watersheds W-1, W-2, and W-3*

Watershed and year	Volume (inches)							Rapid Runoff (percent)						
	1 hr.	2 hr.	6 hr.	12 hr.	1 day	2 days	8 days	1 hr.	2 hr.	6 hr.	12 hr.	1 day	2 days	8 days
W - 1														
1956	0.080	0.160	0.450	0.890	1.710	2.940	5.850	84	83	82	82	81	78	56
1957	.031	.060	.178	.334	.478	.838	1.880	58	55	55	52	33	24	–
1958	.029	.056	.159	.296	.452	.679	1.580	55	52	50	46	29	6	–
1959	.078	.155	.459	.883	1.410	2.790	4.940	83	83	83	82	77	77	48
1960	.103	.205	.612	1.220	2.370	4.510	13.310	87	87	87	87	86	85	81
1961	.024	.045	.110	.202	.336	.437	1.147	46	40	27	21	5	–	–
1962	.040	.080	.200	.370	.580	.970	2.140	68	66	60	57	45	34	–
Average .	0.055	0.108	0.310	0.599	1.048	1.881	4.407	76	74	74	73	69	66	42
W - 2														
1956	0.110	0.210	0.620	1.230	2.280	4.160	8.030	85	84	83	83	82	80	59
1957	.015	.030	.090	.180	.340	.669	2.190	–	–	–	–	–	–	–
1958	.013	.026	.076	.148	.293	.558	1.600	–	–	–	–	–	–	–
1959	.070	.139	.412	.810	1.600	3.080	7.160	76	76	75	74	74	73	54
1960	.037	.074	.219	.430	.840	1.645	5.182	54	54	53	52	51	50	36
1961	.001	.002	.005	.009	.016	.026	.072	–	–	–	–	–	–	–
1962	.021	.042	.125	.248	.480	.920	2.610	19	19	17	16	14	10	–
Average .	0.038	0.075	0.221	0.436	0.836	1.579	3.835	33	33	33	32	32	30	21
W - 3														
1956	0.240	0.470	1.350	2.550	3.140	6.210	8.670	98	97	97	97	95	95	86
1957	.058	.116	.336	.633	1.090	1.630	3.160	90	90	89	88	86	81	61
1958	.029	.057	.166	.320	.559	.852	1.650	80	80	77	76	72	64	25
1959	.094	.183	.538	.998	1.700	2.970	4.570	94	93	93	92	91	90	73
1960	.083	.166	.486	.912	1.656	2.304	4.351	93	92	92	93	91	87	72
1961	.003	.005	.015	.028	.041	.058	.083	–	–	–	–	–	–	–
1962	.035	.070	.204	.400	.770	.992	2.780	83	81	82	81	80	69	56
Average .	0.077	0.152	0.442	0.834	1.279	2.145	3.609	77	76	76	75	74	69	53

and runoff rate. Other flow regimes are superimposed when the watershed soils are near saturation.

Ground water

Water table data were gathered only for watersheds W-2 and W-3. The extensive canal system and use of artesian irrigation in W-1 made the selection of representative well sites difficult. Lack of data for unconfined ground water was partially compensated for by the establishment of recording pressure gages on two representative artesian wells. In this way, data from which estimates could be made for irrigation usage were obtained.

Underflow.–Figures 13 and 14 show the average monthly water table depths for watersheds W-2 and W-3 for 1959-62. Low and high values for the months of record and 24-hour maximums and minimums show that water tables range from ground surface to a depth of about 5 feet.

Figure 15, parts 1 and 2, shows the areal distribution of average ground water depths on these watersheds during the warmer months of high evapotranspiration, and during the cooler months. These periods were selected to demonstrate the variability of water tables during periods of maximum and minimum rates of evapotranspiration. Part 3 shows average annual ground water depths. Part 4 shows water surface contours (m.s.l.) for an average year. Water tables are approximately parallel to ground surface over the watersheds.

Figure 16 is a composite water table recession curve derived from stage observations during rain-free periods. The curves reflect water lost by gravity drainage and evapotranspiration.

Figure 17 shows absorption and desorption characteristics of the upper soil horizons in response to water

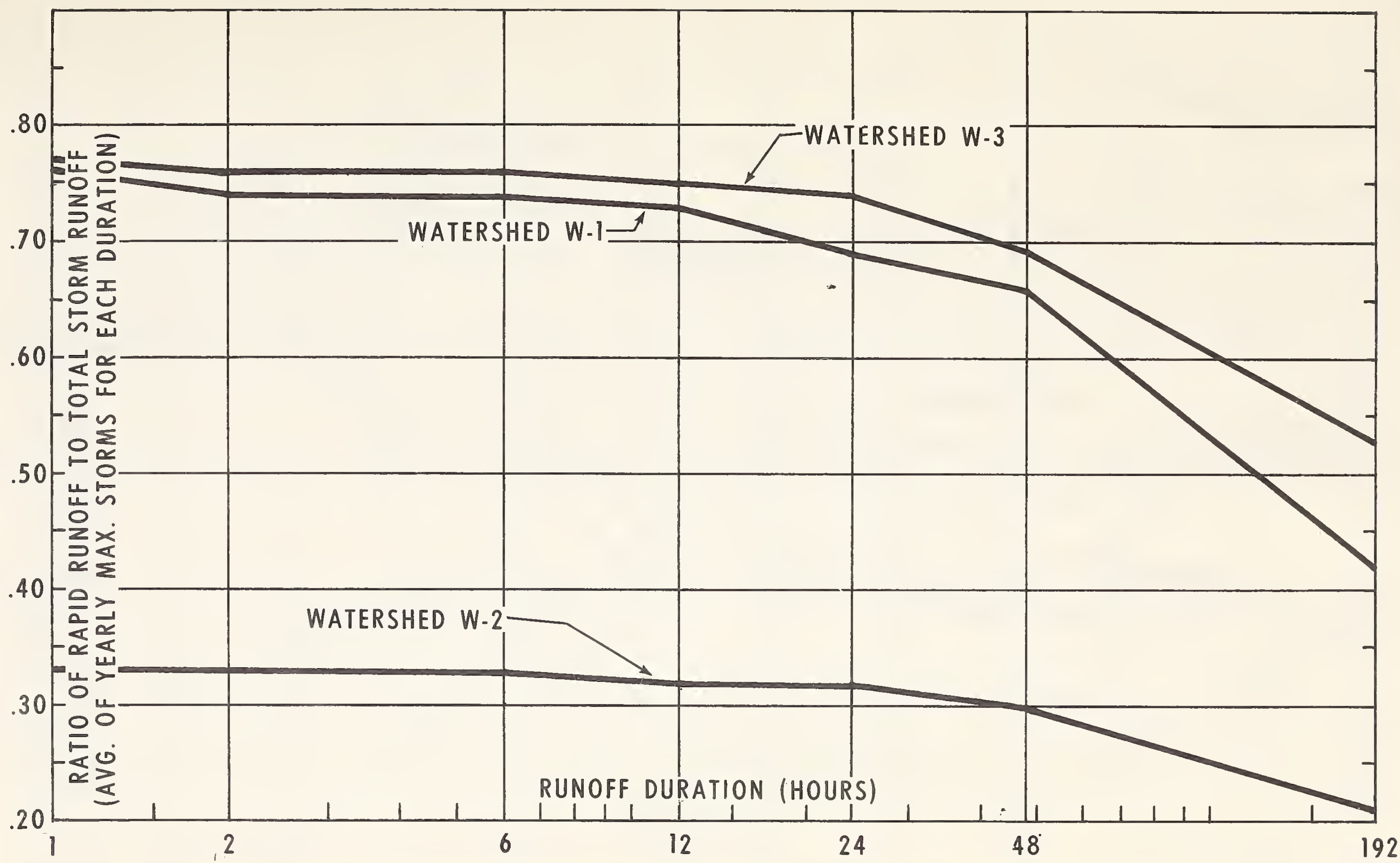


Figure 12.—Ratio of maximum runoff volumes attributable to rapid runoff for selected periods, watersheds W-1, W-2, and W-3. (Values are based on an average of seven maximum runoff events during the period 1956-62.)

Fig. 13

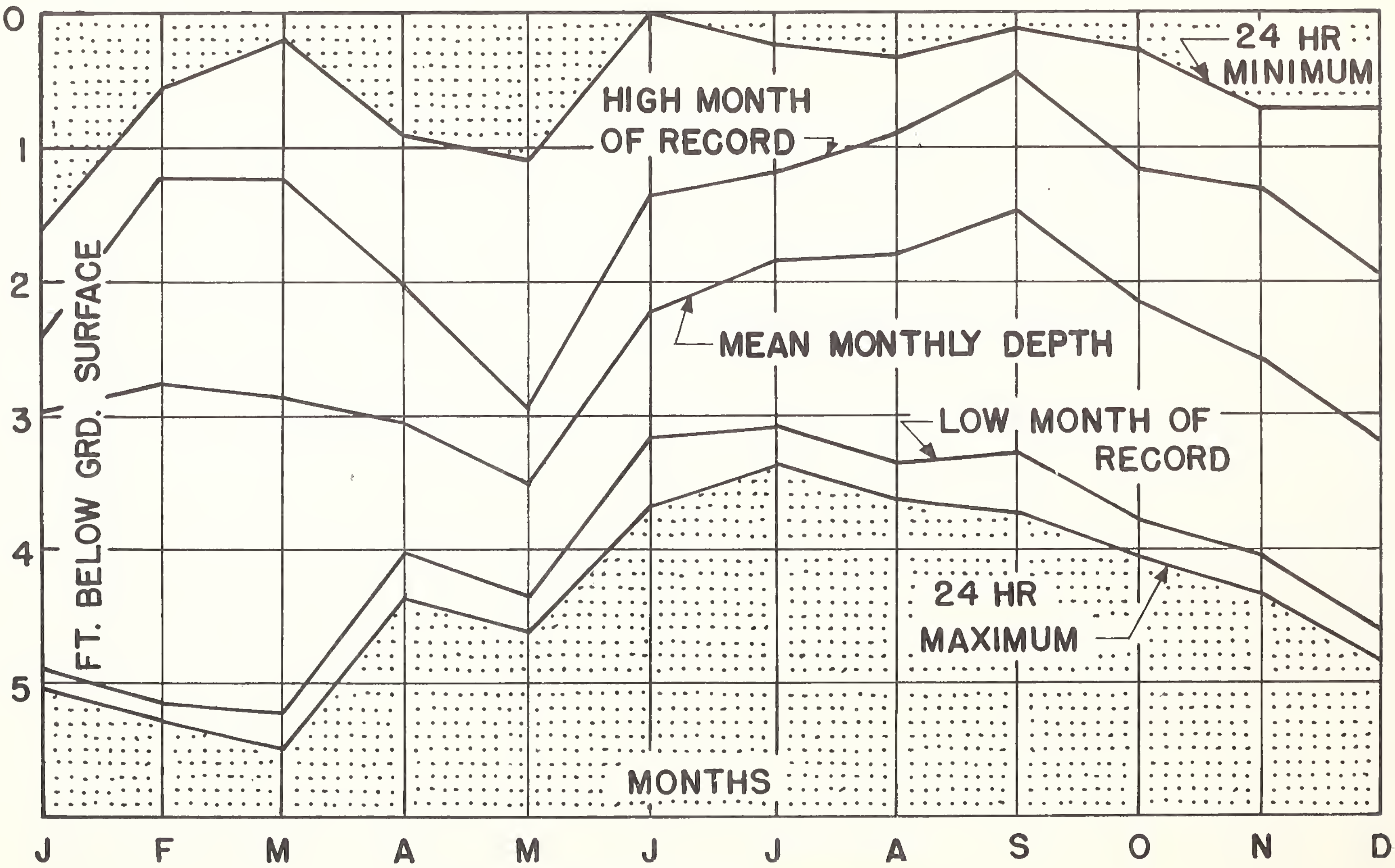


Figure 13.—Average monthly ground water depths on watershed W-2.

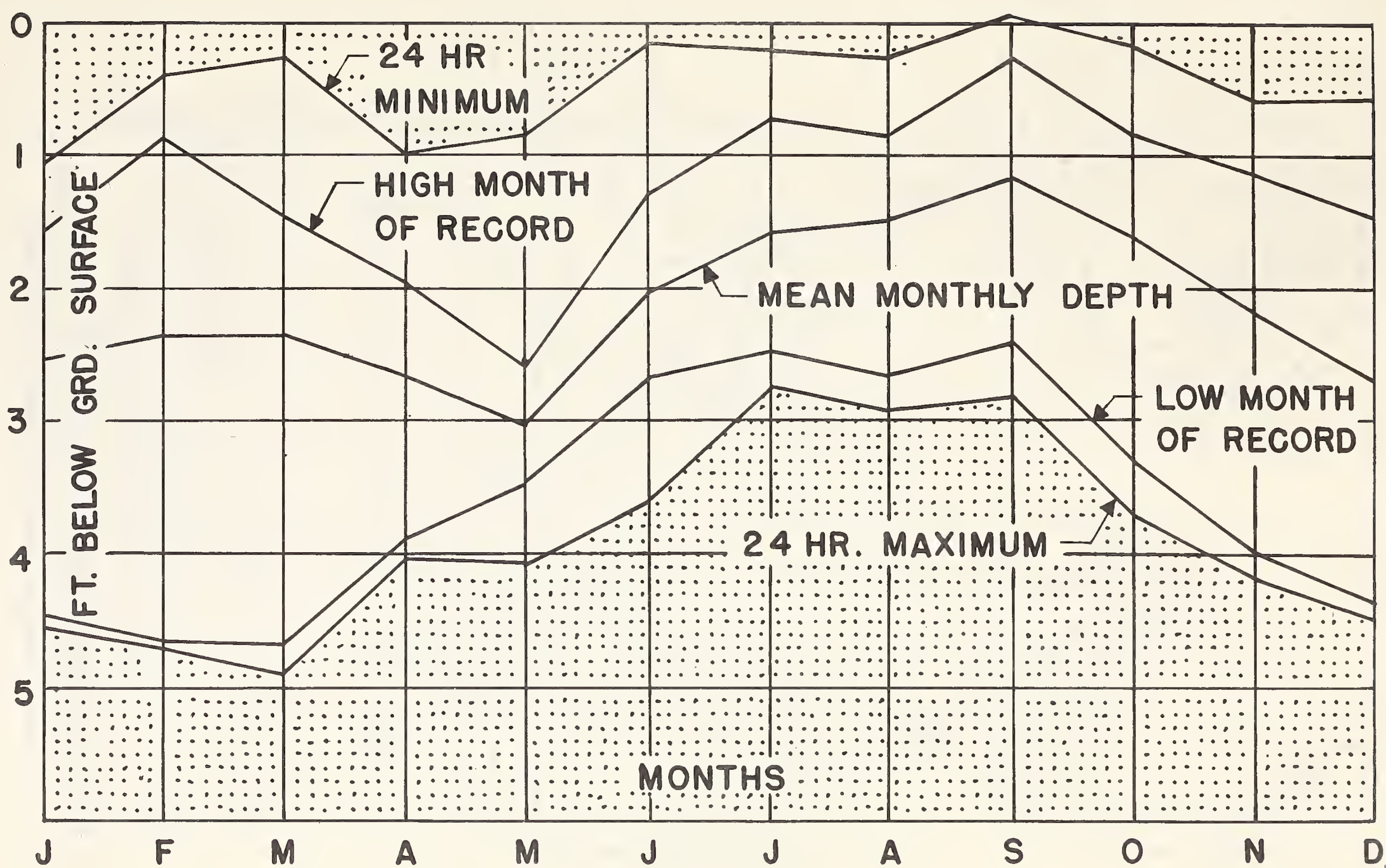
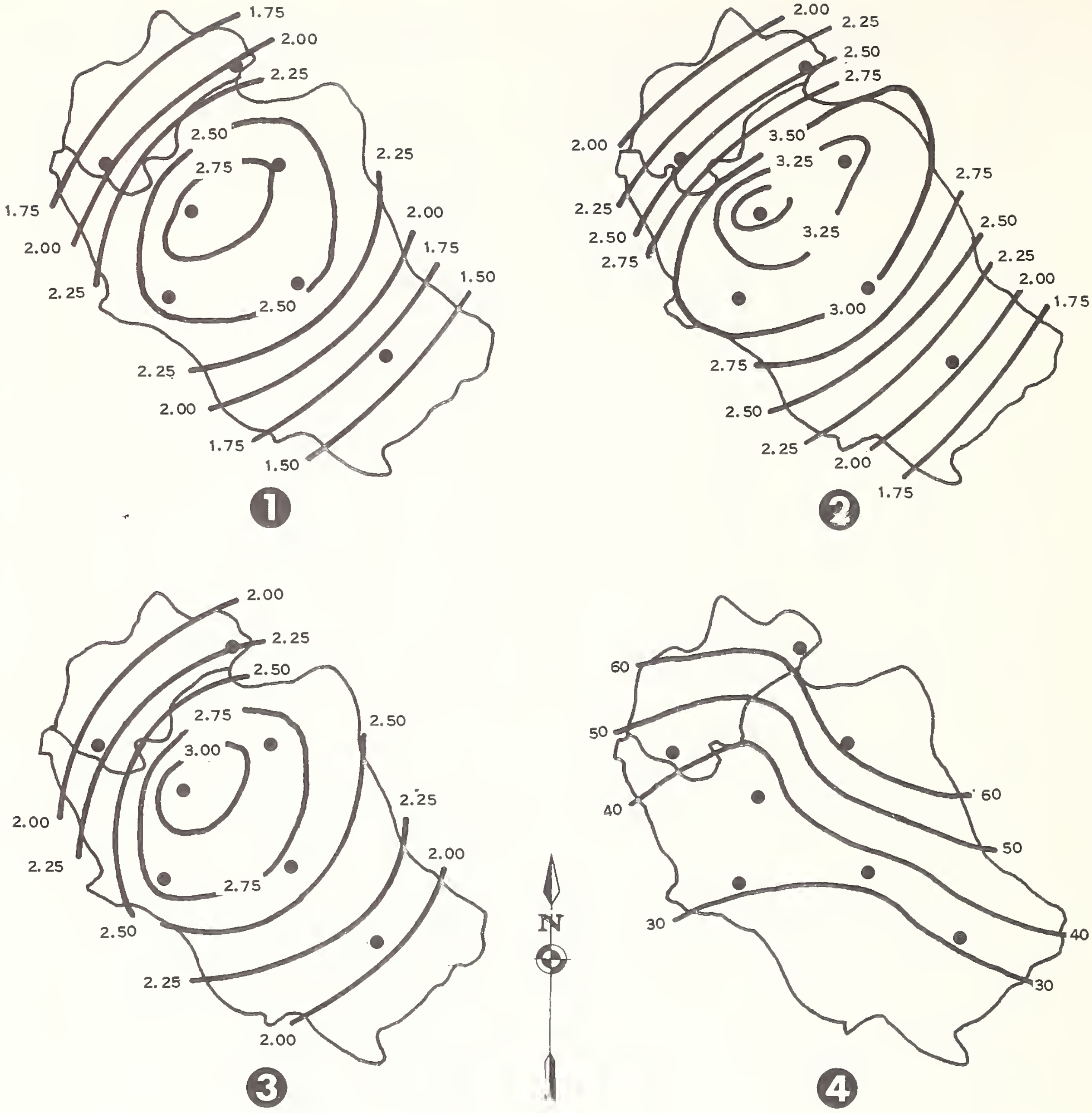


Figure 14.–Average monthly ground water depths on watershed W-3.



- WELL SITES

1. AV. DEPTH BELOW GROUND SURFACE - MAR., APR., MAY, JUNE, JULY, AUG., SEPT., OCT.
2. AV. DEPTH BELOW GROUND SURFACE - JAN., FEB., NOV., DEC.
3. AV. DEPTH BELOW GROUND SURFACE - ALL SEASONS
4. WATER SURFACE CONTOURS (FT. MSL) - ALL SEASONS

Figure 15.–Mean ground water depths, Florida watersheds W-2 and W-3.

Fig. 16

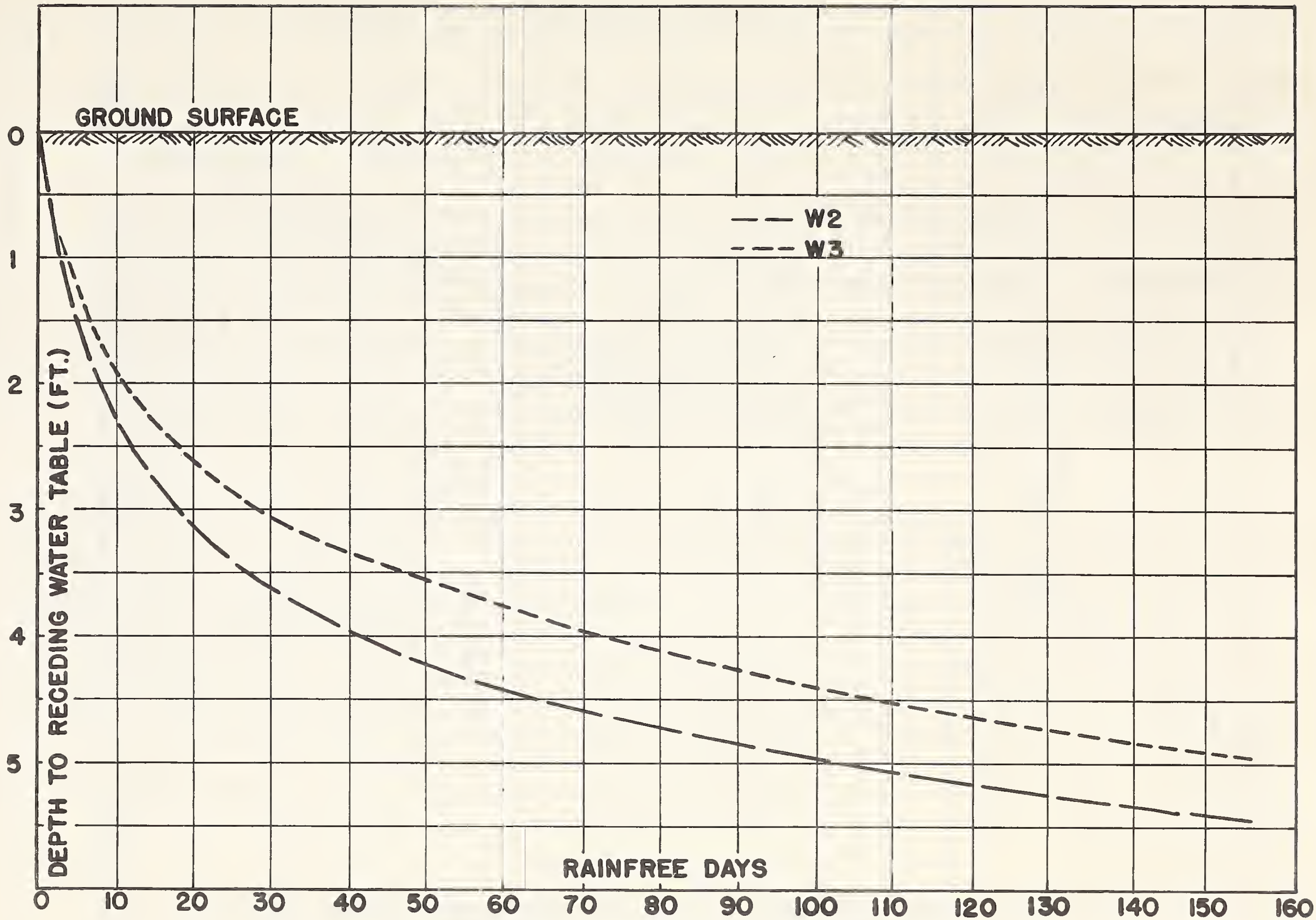


Figure 16.–All-season composite ground water recession curves, watersheds W-2 and W-3

Fig. 17

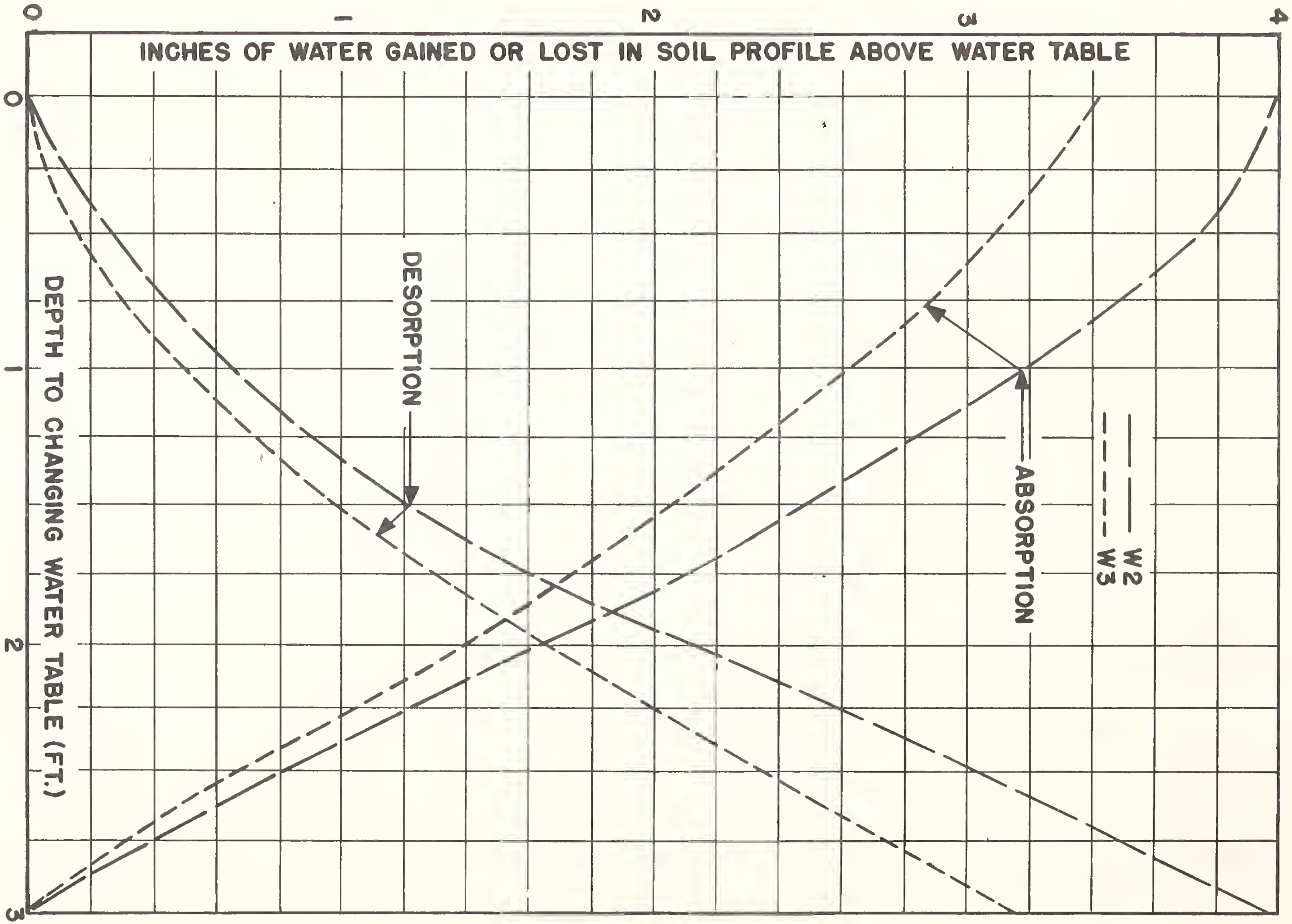


Figure 17.–Composite moisture absorption and desorption curves characteristics of the soils of watersheds W-2 and W-3. Air was evacuated from soil core samples before obtaining soil moisture relations. The curves represent maximum possible soil moisture release and retention.

table changes. These curves were derived by laboratory soil sample testing, and are modal composites of soil core data from each of seven recorder sites. A depth of 3 feet is the maximum depth shown for these curves; below this depth the sandy soils could not be core sampled because of the high degree of saturation.

Ground water recharge.–Maximum ground water recharge, or upper aquifer storage capacity, is approximately equal to existing pore space in the soil profile minus entrapped air. Most of southern Florida's soils are highly permeable. Information concerning the amount of rainfall a given soil will absorb without appreciable rapid runoff is essential in determining the water storage and release characteristics of agricultural watersheds.

Data on changes in water table levels due to rainfall have been obtained for a number of years from seven observation sites on Taylor Creek Watershed (W-2). With water tables closer than 2.5 feet to ground surface, major rainfall events produced surface flooding which nullified the use of these measurements to determine ground water rise. Water tables were seldom below 4.5 feet during the recharge season, when sufficient rain to produce significant water table rise usually occurs. Therefore, rainfall events were selected with initial water tables within this range, with a minimum of 24 hours without rainfall before and after the event. Rainfalls ranged from 0.80 inch to 2.20 inches and averaged 1.39 inches for the 74 selected events over a 5-year period.

Figure 18 shows the regression line and correlation coefficient for the relationship of rainfall to water table rise. The regression equation is $Y = 0.87X - 0.26$ where the rainfall, X, is in inches and the water table rise is in feet, with a correlation coefficient, r, of 0.787. A linear relation was assumed in this figure. The regression line was developed from data obtained from 74 rainfall events and corresponding water table rises at the seven individual observation sites. The coefficient of determination, r^2, of 0.619 indicates that 62 percent of the variation in water table rise is associated with amount of rainfall alone. For comparison, six selected rainfall events were weighed by the Thiessen method, and plotted against the average rise in water table for the entire watershed. The resulting coordinate points (large dots) were superimposed on the computed regression line shown in figure 18. Agreement between the two methods of predicting water table rise with rainfall amounts is reasonable, at least within the specified initial water table depths.

Types of Flow

Semilogarithmic plottings or storm discharge hydrographs and follow up analyses of the recession limbs of these hydrographs have shown that three characteristic flow regimes occur on all three watersheds. Five major storms were analyzed by the Barnes method (1) for all three watersheds. In figure 19, K_2 is the amount of time in days that it takes recession q to cross one log cycle; Δq is the change in recession flow rate; and ΔS is the change in basin storage.

Then $M = \frac{\Delta q}{\Delta S} = \frac{2.3}{K_2}$, where M is slope of the flow rate vs. storage curves. Also,

A = lower limit of base flow (slow);
B,E,H, = lower limit of interflow (intermedial); and
C,F,I, = lower limit of direct runoff (rapid flow).

Because they express runoff rates in inches per day, these curves compare the recession flow characteristics of the three watersheds. The relationships between flow rate and storage for base flow from watersheds W-1 and W-2 are similar; the slope of AB is only 9 percent greater than the slope of AE. Since these watersheds have similar soils and slopes, this result might be expected. However, because the slope of the flow rate/storage relationship of intermedial and rapid flow is steeper for watershed W-1 than W-2, the difference in drainage density of their flow channels is apparent. The slope of this recession relationship for intermedial flow is 26 percent greater, and the slope for rapid flow is 20 percent greater, for W-1 than for W-2. Better drainage in W-1 is also shown by the rates at which the flow regime characteristics change. Rapid flow continues until the rate reaches 0.31 inch per day on the well-drained W-1 watershed, where surface water has ready access to drainage channels. On the undeveloped W-2 watershed, surface drainage ceases and interflow occurs when the flow rate reaches 0.41 inch per day.

On the smaller watershed (W-3), faster drainage is shown by the steeper slopes of lines AH, HI, and IJ. Base flow rate for W-3 is approximately 44 percent greater than the base flow rate for W-1. Faster recession rates for all flow types are assumed to be due to steeper slopes, high gradient channels, and probably more permeable soils in W-3 than in W-1 and W-2.

A comparison of the curves in figure 19 shows that during periods of rapid runoff (CD, FG) approximately 0.3 inch more basin storage is available to runoff on W-2 than on W-1. Since rapid runoff is an indication of surface flooding, this additional volume suggests a longer period of surface flooding for W-2. This divergence in flow characteristics occurs because of the extended intermedial rate (EF) of W-2.

On the smaller watershed (W-3), direct runoff ceases at a flow rate of 4.1 c.f.s. per square mile with only about 0.5 inch of basin storage available to runoff as intermedial and slow flow.

Fig. 18

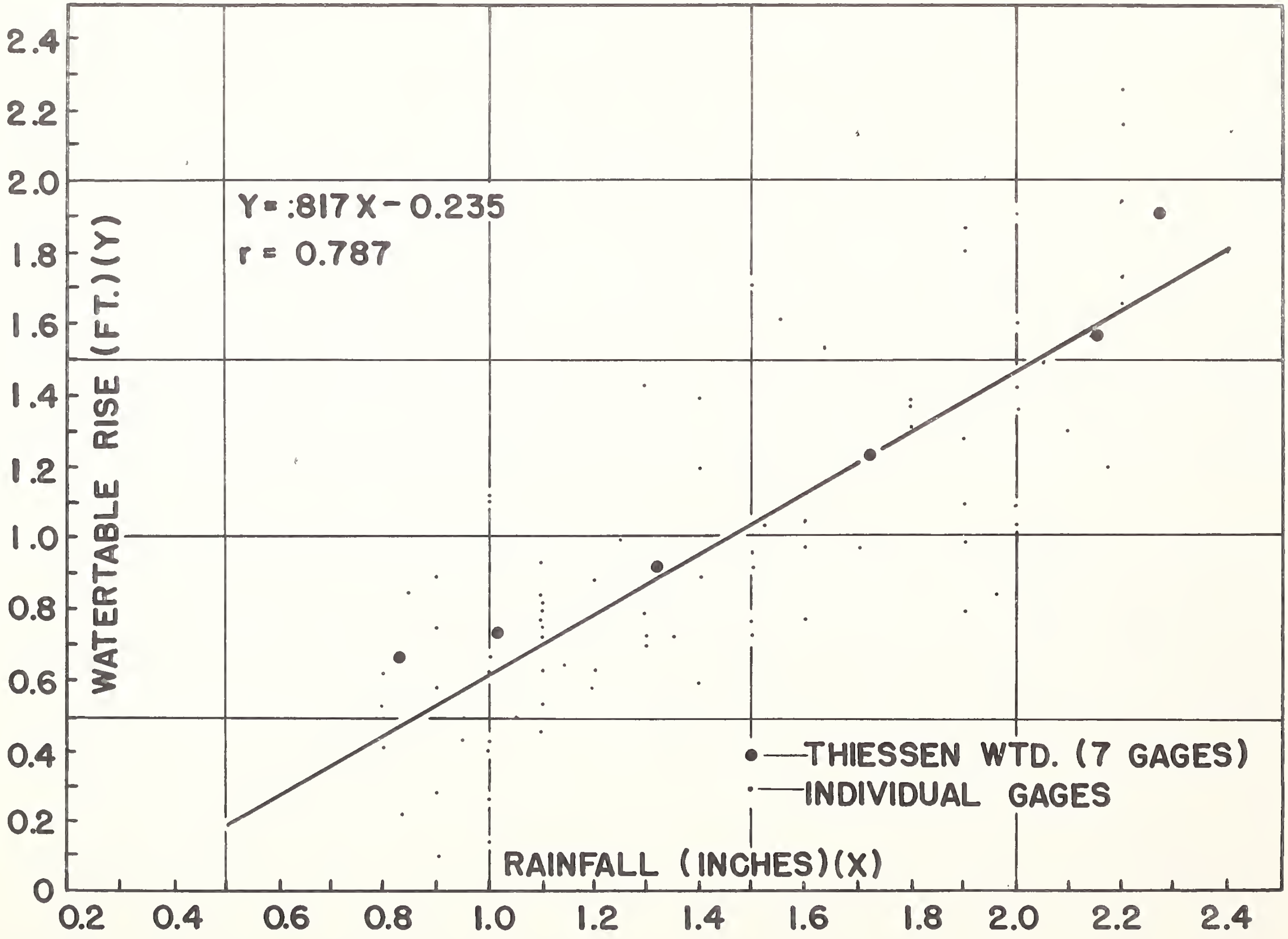


Figure 18.–Changes in water table levels with rainfall, developed from field data for watershed W-2

The limits of these flow characteristics vary with individual runoff events. Curves shown in figure 19 were averaged from several storm runoff events. Rainfall distribution, spatial and temporal, affects the pattern on all three watersheds. With increased watershed development, the lower limits of direct runoff from watershed W-2 probably will be lowered to a flow rate more like that of W-1.

The curves are useful in estimating the water budget for given periods. Change in water storage within the watershed during the selected period can be estimated by comparing flow rates at the beginning and end of the period. The difference in basin storage is added to, or subtracted from, the P-R (Precipitation-Runoff) relationship to estimate evapotranspiration. However, when water tables reach a depth of about 30 inches, soil moisture volumes held at tensions below field capacity may vary widely. These volumes are not reflected in the curves of figure 19.

Figure 20 shows a comparison of the three types of flow regimes that occur on the three watersheds. The graph also shows the distribution in time, by years, and the proportion of component flows for individual watersheds. Table 6 lists the annual volume of flow components (inches) and percentage of annual total runoff for the three watersheds.

Maximum 24-hour Rates (11)

The nature of flood flow depends on the physiographic and climatological setting of a stream's drainage basin. The dominant, and often the only readily obtainable, basin characteristic is size. In this case, the flood-flow equation may be expressed as $q = C M^x$. This equation is similar to the Cypress Creek formula $q = C M^{5/6}$, where q is the average runoff rate in cubic feet per second for the 24-hour period of greatest runoff for a storm event; M is drainage area in square miles; and C is a coefficient based on rainfall frequency and topography. To use the general equation $q = C M^x$, however, values must be determined for the exponent x and the coefficient C.

To determine these values from the experimental watershed data, it was necessary to obtain a rainfall excess value for storm events on the watersheds to compare the relationship between rainfall and runoff. The following moisture budget method was applied to the 30-day period prior to each storm event to obtain this value.

The amount of water stored in the soil decreased during rain-free periods in accordance with the equation $I_t = I_o K^t$, where I_o is the initial amount of water stored in the soil, I_t is the reduced amount t days later, and K is the recession factor. Values of K equal to 0.96 for winter months and 0.94 for other months in southern Florida were obtained from observed ground water recession curves and laboratory-determined desorption curves. In the moisture budget method, the water table was assumed to be at ground surface with 5 inches of evaporable water in storage 30 days prior to storm runoff. Though not strictly true, error in this assumption was usually negligible over a 30-day period. Storm rainfall excess was obtained by subtracting the computed water storage available in the soil at the beginning of the storm event from the total measured storm rainfall.

To establish M^x relations, the equation $q = C M^x$ was analyzed graphically by plotting on logarithmic paper maximum 24-hour average runoff rates against watershed areas for the 10 maximum annual storms of record for watershed W-1 (1951-60) and the 5 maximum annual storms for watersheds W-2 and W-3 (1956-60).

Figure 21 shows the resultant equations fitted to peak daily flows from computed rainfall excess amounts of 7, 5, and 2 inches. Corresponding total rainfalls for the individual storms were about 10, 8, and 5 inches. Most of these storms lasted about 24 hours. Such events were estimated from frequency charts (4) to occur on an average of once in 50, 10, and 2 years, respectively.

The best fitting equation, $q = 131 M^{0.83}$, was obtained from annual maximum 24-hour average runoff rates following the largest storms on record. The lower lines, $q = 115 M^{0.79}$ and $q = 97 M^{0.63}$, were established by interpolation for computed excess amounts of rainfall of 5 and 2 inches.

Values of the coefficient C in the Cypress Creek formula were computed from annual maximum 24-hour average runoff rates for the three watersheds using the formula $C = q/M^{5/6}$.

Figure 22 shows these C values plotted as functions of excess rainfall for all major storms. Based on 20 runoff events, and computed by the method of least squares, the regression equation is $C = 16.39 + 14.75 Pe$, where Pe is excess rainfall (inches) for the individual storm periods. The correlation coefficient r, the coefficient of determination r^2, and the 50- and 95-percent confidence limits were computed and are shown in figure 22.

The estimated return frequency of excess rainfall was derived from the relation of excess rainfall to total storm rainfall, and the statistical frequency of the latter. These excess rainfall frequencies are essentially the return frequencies of 24-hour rainfall amounts on the three watersheds, minus about 3 inches for soil storage.

The accuracy of the exponent in the Cypress Creek formula $q = C M^{5/6}$ for the 50-year storm frequency is

Fig. 19

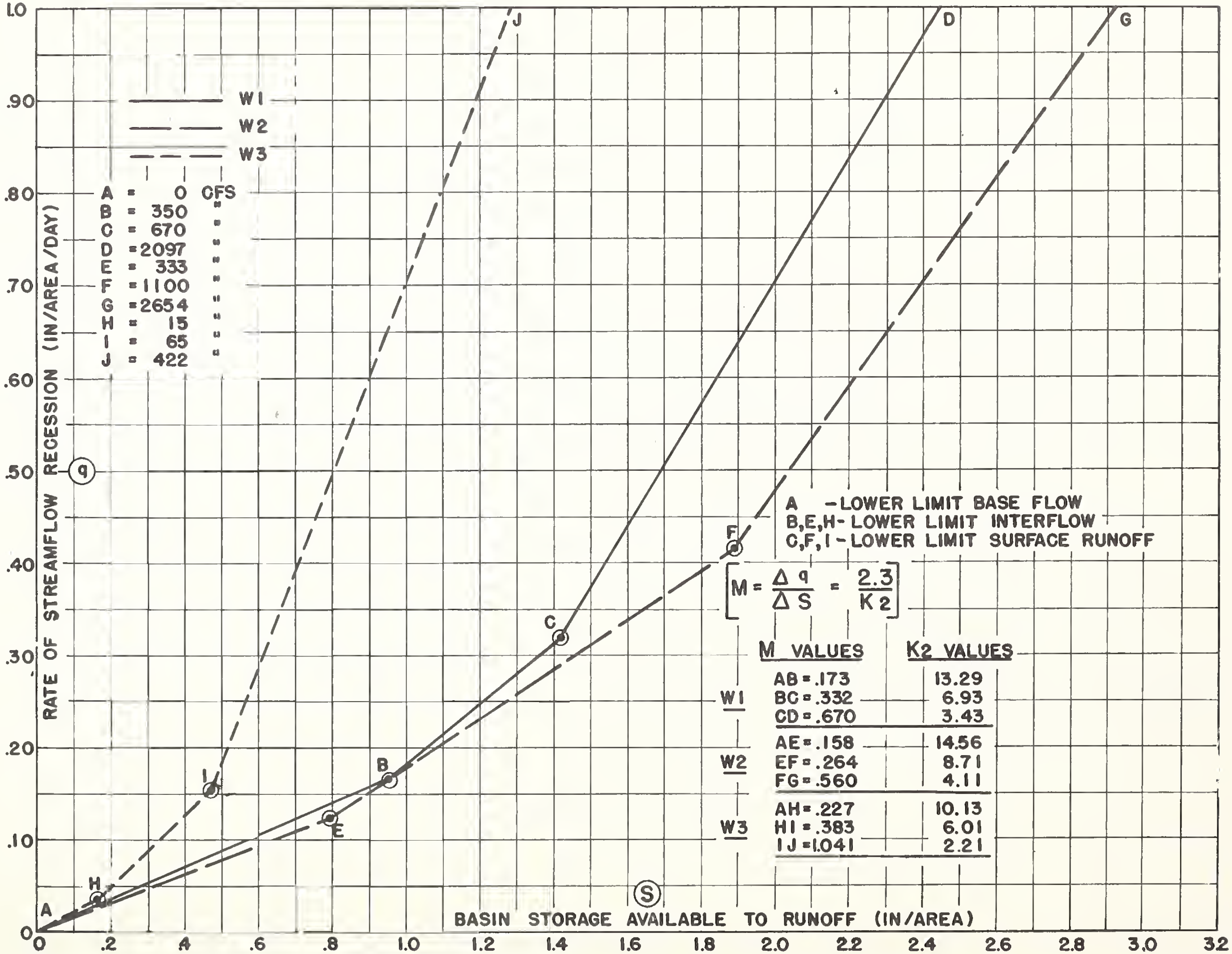


Figure 19.–Lower limits of types of flow regimes, and basin storage available to runoff at various flow rates. Watersheds W-1, W-2, W-3.

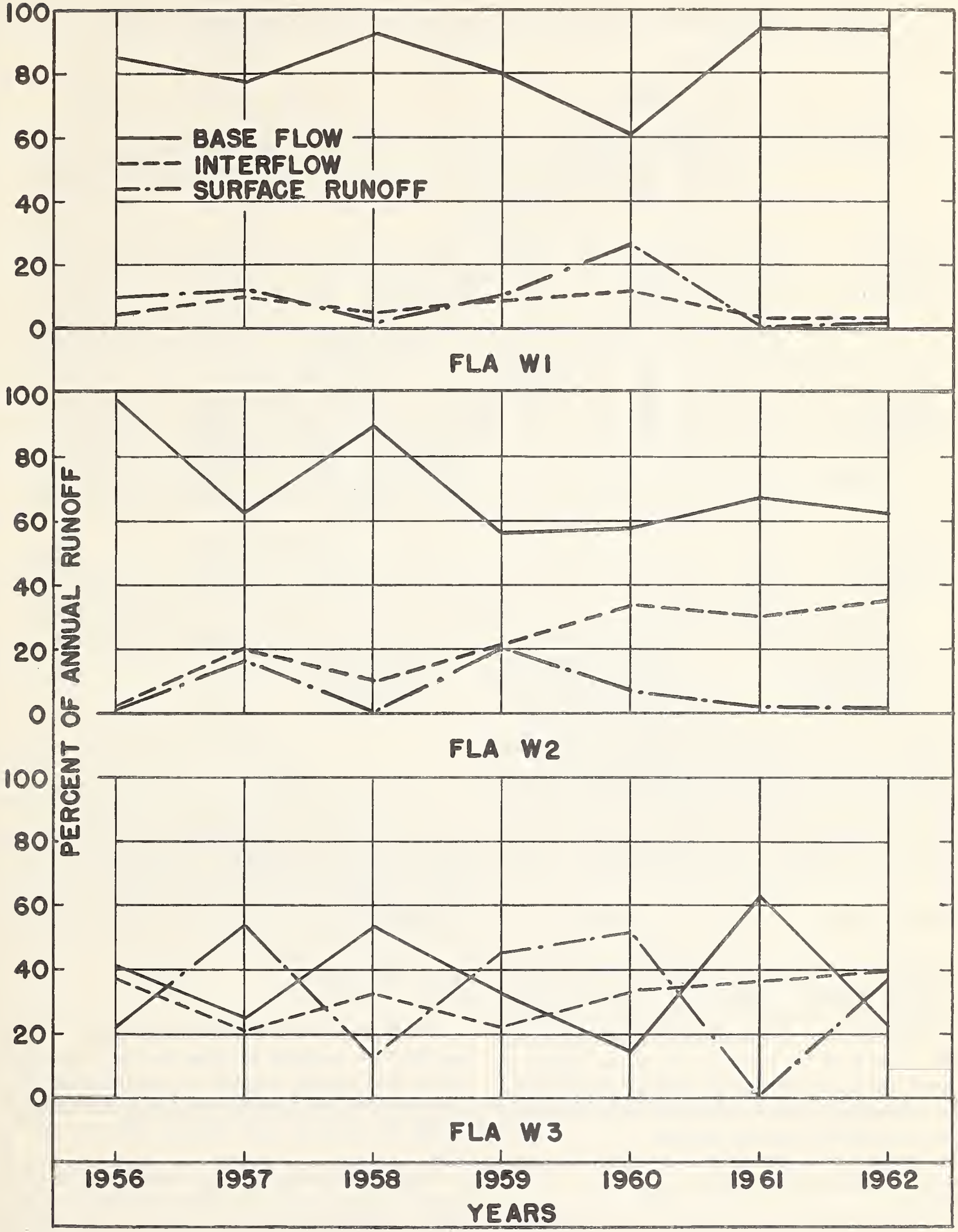


Figure 20.–Time distribution of annual flow volumes in percentage of total annual runoff by types of flow regimes for watersheds W-1, W-2, and W-3.

TABLE 6.—*Annual volume of runoff by type of flow and percentage of annual runoff in each type of flow, watersheds W-1, W-2, and W-3*

Watershed and type of flow	1956		1957		1958		1959		1960		1961		1962	
	Volume	Percentage of runoff	Volume	Percentage of runoff	Volume	Percentage of runoff	Volume	Percentage of runoff	Volume	Percentage of runoff	Volume	Percentage of runoff	Volume	Percentage of runoff
W - 1	*In.*	*Pct.*	*In.*	*Pct.*	*In.*	*Pct.*	*In.*	*Pct.*	*In.*	*Pct.*	*In.*	*Pct.*	*In.*	*Pct.*
Base flow[1]	13.30	85	24.24	78	18.31	93	22.18	80	26.87	61	17.00	95	24.43	94
Interflow[2]	.83	5	3.07	10	.96	5	2.50	9	5.30	12	0.72	4	0.89	4
Overland flow[3]	1.45	10	3.82	12	.36	2	3.17	11	12.03	27	0.14	1	0.50	2
Total runoff	15.58	100	31.13	100	19.63	100	27.85	100	44.20	100	17.86	100	25.82	100
W - 2														
Base flow[4]	4.31	98	18.83	63	11.14	90	11.14	57	19.53	58	3.34	68	10.74	63
Interflow[5]	.07	2	6.09	20	1.29	10	4.35	22	11.89	35	1.44	30	6.09	36
Overland flow[6]	0	0	5.06	17	0	0	4.07	21	2.39	7	0.10	2	0.14	1
Total runoff	4.38	100	29.98	100	12.43	100	19.56	100	33.81	100	4.88	100	16.97	100
W - 3														
Base flow[7]	2.14	41	5.67	25	5.36	54	3.87	33	4.77	15	1.34	63	3.26	23
Interflow[8]	1.93	37	4.66	21	3.19	33	2.52	22	10.70	33	0.78	37	5.68	40
Overland flow[9]	1.11	22	12.12	54	1.30	13	5.19	45	16.54	52	0.00	0	5.22	37
Total runoff	5.18	100	22.45	100	9.85	100	11.58	100	32.01	100	2.12	100	14.16	100

[1] Less than 350 c.f.s.
[2] 350 to 670 c.f.s.
[3] Over 670 c.f.s.
[4] Less than 333 c.f.s
[5] 333 to 1,100 c.f.s
[6] Over 1,100 c.f.s
[7] Less than 15 c.f.s
[8] 15 to 65 c.f.s
[9] Over 65 c.f.s

indicated by the good fit of the regression line $q = 131 M^{0.83}$. Although the exponent decreases for smaller storms, the exponent 5/6 will produce safe design runoff values and we recommend its use. The value of C obtained from figure 22 can be adjusted to give observed runoff rates for smaller storms.

Minimum Rates

Low flow data (table 7) were treated according to the Hazen method to obtain predicted occurrence frequency of various low flow rates for 7-, 14-, and 30-day periods for watershed W-2. Low flow data were not analyzed for W-1 because of the influence of artesian inflow on runoff during low flow periods. Because watershed W-3 has experienced periods of zero flow almost annually, it was unsuitable for frequency analysis.

Low flow rates were plotted on probability paper (fig. 23) according to the formula:

$P = \frac{2m-1}{2n}$, where P is the plotting point on the probability scale,

m is the rank of the term to be plotted; and

n is the total number of terms in the series.

The Hazen method of adjusting for skew of low flows was used to determine the frequency curves shown in figure 23. From Hazen's table of logarithmic skew-curve factors (3) the standard deviations, above or below the mean, corresponding to several probabilities were obtained, and with this information the curves were drawn.

Flow Durations

Flow duration characteristics of watersheds W-1, W-2, and W-3 are compared in figure 24. The influence of inflow from artesian irrigation on runoff for about 60 percent of the time is clearly indicated by the "plateau" in the W-1 duration curve between 100 c.f.s. and 50 c.f.s.

Rapid flow (surface runoff) occurs during approximately 2 percent of the time for both W-1 and W-2 (flows exceeding 670 c.f.s. for W-1, and 1,100 c.f.s. for W-2), and represents 9 percent of the total annual runoff from W-1, and 7 percent from W-2. The flow duration curves are similar for both watersheds during rapid flows

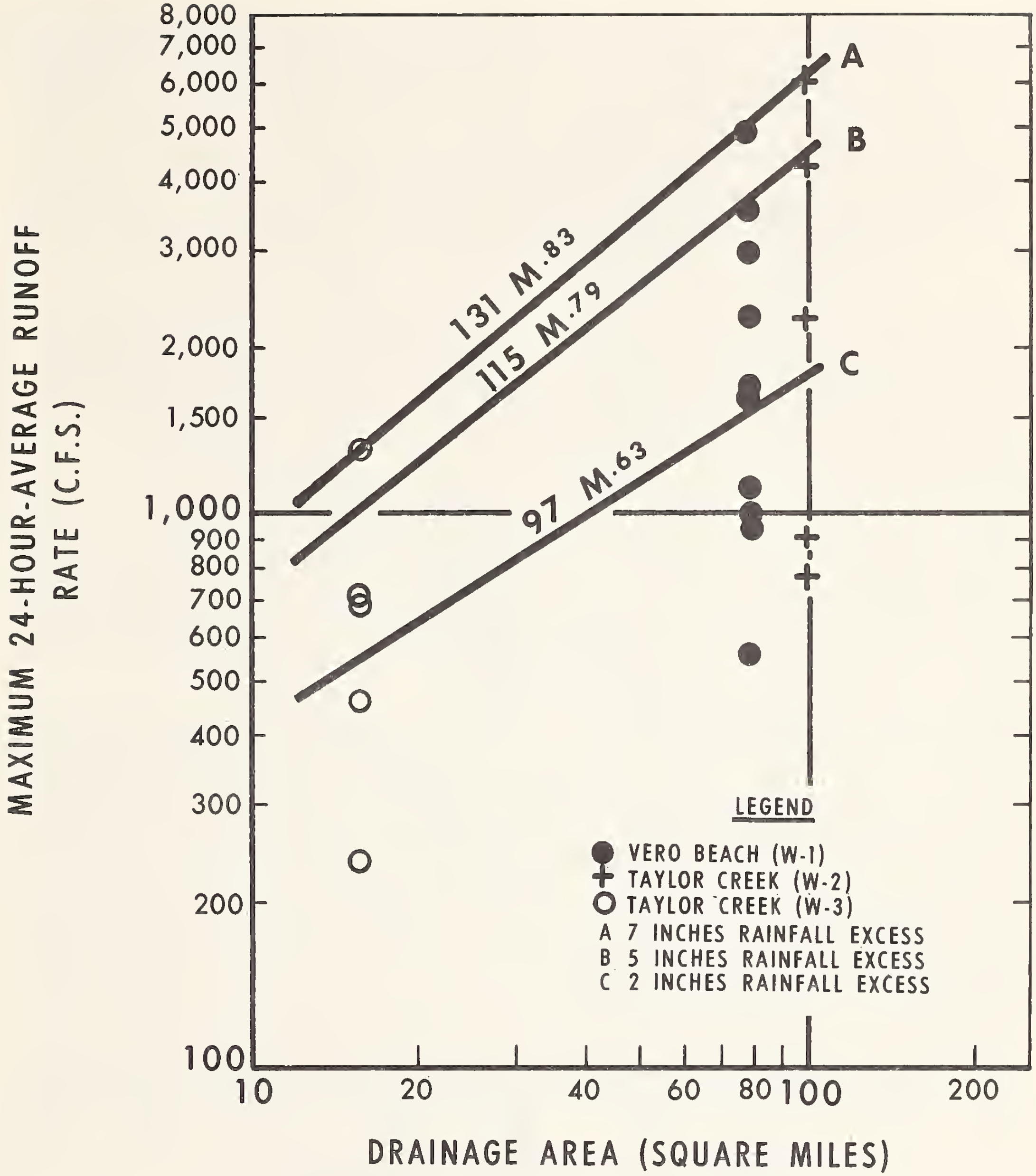


Figure 21.–Relationship of annual maximum 24-hour average runoff rate to drainage area for three experimental watersheds in southern Florida.

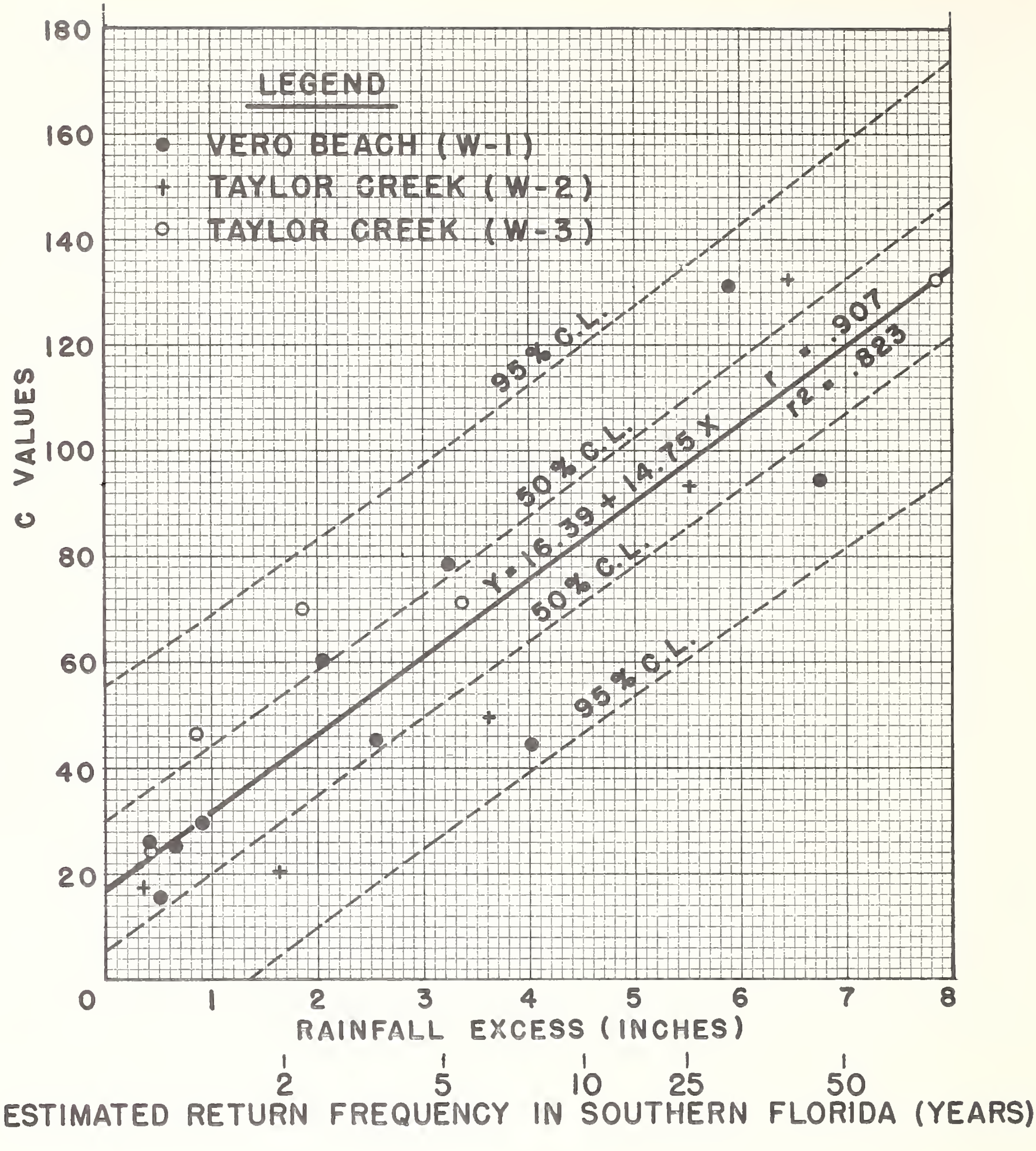


Figure 22.–Values of C in the Cypress Creek formula $q = C M^{5/6}$, versus excess rainfall for three experimental watersheds in southern Florida.

TABLE 7.–*Low flow rates of runoff from Uper Taylor Creek (Watershed W - 2) for period of record (July 1955 - June 1964)*

Year ending June 30	7-day rate	14-day rate	30-day rate
	c.f.s.	*c.f.s.*	*c.f.s.*
1956	0	0	0
1957	1.0	1.1	1.3
1958	1.3	1.7	4.1
1959	4.0	4.5	7.6
1960	4.4	5.1	7.8
1961	.1	.2	.5
1962	.8	.9	1.1
1963	1.8	1.9	2.3
1964	2.1	2.2	2.8
[1] S =	0.910	0.908	0.952
[2] C.S. (Adj.)	1.30	1.42	1.41

[1] Standard deviation.
[2] Adjusted coefficient of skew (values relative to mean of series.)

but the *volume* of rapid flow from W-1 (3.07 inches per year) is nearly twice that of W-2 (1.68 inches per year).

The high average volume of rapid flow per year on watershed W-1 is probably due to reduced available water storage in the soil, because of extensive artesian irrigation prior to major storms. The fact that W-1 can dispose of this additional rapid flow in the same amount of time as W-2 indicates the effect of drainage.

Unit Hydrographs

Two runoff events, occurring on October 15-24, 1956, and June 17-26, 1959, on both watersheds W-1 and W-2, were selected for unit hydrograph development. Primary considerations in selecting storm events were high rates of runoff and isolation from other rainfall events. Runoff for the October 1956 event could be related to one 24-hour period of excess rainfall. Runoff hydrographs for the June 1959 event were altered slightly by subtracting hydrographs for small amounts of excess rainfall before and after the principal 24-hour excess rainfall period.

The development of unit hydrographs from storm runoff hydrographs required the extraction of base flows (slow flows) to obtain the runoff hydrographs of rapid and intermedial flow associated with the selected events. The average upper limits of base flow are 350 c.f.s. for watershed W-1 and 333 c.f.s. for W-2. Because the selected events were isolated from other rainfall events, flow rates at the beginning of the events were lower than these average limits. The volume of base flow was obtained graphically by assuming the base flow rate increased uniformly from the beginning of the event until it reached the upper limit of base flow at the time of peak flow. This upper limit of base flow was then assumed to continue for the remainder of the hydrograph. All flow below the limit of base flow was subtracted from the storm runoff hydrograph. The flow volume remaining under the hydrograph was classified as rapid and intermedial runoff.

The unit hydrographs for watersheds W-1 and W-2 were constructed for both storms from the respective hydrographs of rapid and intermedial flow. The ordinates of the unit hydrograph (inches per hour) were proportioned according to the ratio of the unit hydrograph runoff volume (1 inch) to the rapid and intermedial runoff volume. The unit hydrographs for both storms were then graphically combined by averaging ordinates and smoothing curves to obtain a representative 24-hour unit hydrograph for each watershed. These unit hydrographs, shown in figure 25, can be used as runoff distribution graphs of excess rainfall on watersheds W-1 and W-2.

Development of design runoff hydrographs for 24 hours of excess rainfall on the Southern Florida Flatwoods Land Resource Area should follow this procedure:

(1) Estimate the amount of excess rainfall from predicted rainfall and from antecedent soil moisture condition;

(2) Develop the hydrograph of rapid and intermedial flow from the unit hydrograph (fig. 25) by multiplying unit hydrograph ordinates by excess rainfall; and

(3) Add base flow.

Rainfall-Runoff Relationships

Figure 26 shows the relation of annual rainfall to runoff for watersheds W-1, W-2, and W-3. The curves are derived from measured runoff against measured rainfall for watersheds W-2 and W-3. For watershed W-1, measured runoff includes inflow from extensive artesian irrigation. To compare rainfall-runoff characteristics of this watershed (W-1) with those of W-2 and W-3, computed irrigation was abstracted from measured runoff, and the resulting curve was plotted as "adjusted" runoff.

The unadjusted curve for W-1 shows the influence of artesian irrigation on runoff. Variations in annual irrigation depend on the amount and temporal distribution of rainfall. Normally, irrigation is greatest during January, February, April, May, November, and December. Generally, little irrigation is needed when annual rainfall approaches 60 inches. The large amount of irrigation in 1960, when the annual rainfall was 73 inches, was due to

Fig. 23

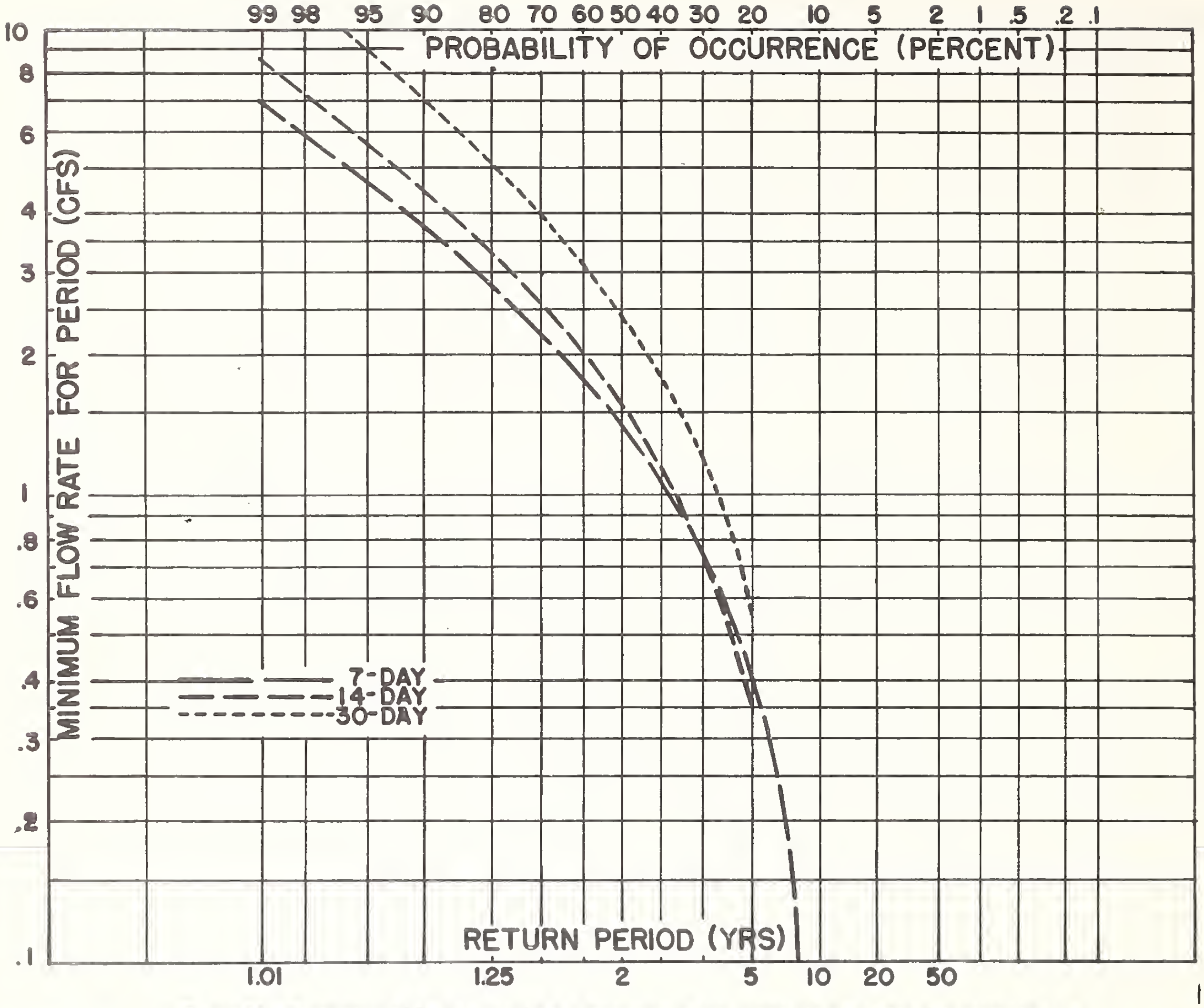


Figure 23.–Frequency of 7-, 14-, and 30-day minimum flows, Upper Taylor Creek, (Watershed W-2) July 1955-June 1964, Hazen method.

abnormal rainfall distribution. Hurricane rainfall in September (21.23 inches) contributed disproportionately to the annual volume. If the hurricane rainfall is abstracted from the annual total, the irrigation usage approximates the amount used when the rainfall volume is about 55 inches.

Measured runoff has been approximately 14 percent less on W-3 than on W-2 with equal annual rainfalls above 40 inches. This might be because the ratio of outflow seepage boundary to area is much larger for W-3 than W-2. Consequently, the percentage of lateral ground water outflow through the surface sandy mantle, above the impervious lower formation, from the smaller watershed (W-3) is larger. Since about half of this boundary lies *within* the area of W-2, outflow seepage not measured as W-3 runoff would eventually contribute to W-2 runoff.

From the data in figure 26, annual runoff for the Southern Florida Flatwoods can be predicted with reasonable accuracy by equations:

(W-1) – $Q = 0.91\ (P\text{-}35)$

(W-2) – $Q = 0.97\ (P\text{-}35)$

(W-3) – $Q = 0.83\ (P\text{-}35)$ where Q = expected yearly runoff in inches; P = annual rainfall in inches.

These values are based on rainfall exceeding 40 inches annually. The larger watersheds apparently contribute about 94 percent of the rainfall exceeding 35 inches to measured runoff; the smaller watershed contributes about 83 percent. When annual rainfalls drop below 40 inches, runoff is usually between 2 and 5 inches. These small volumes are not predictable.

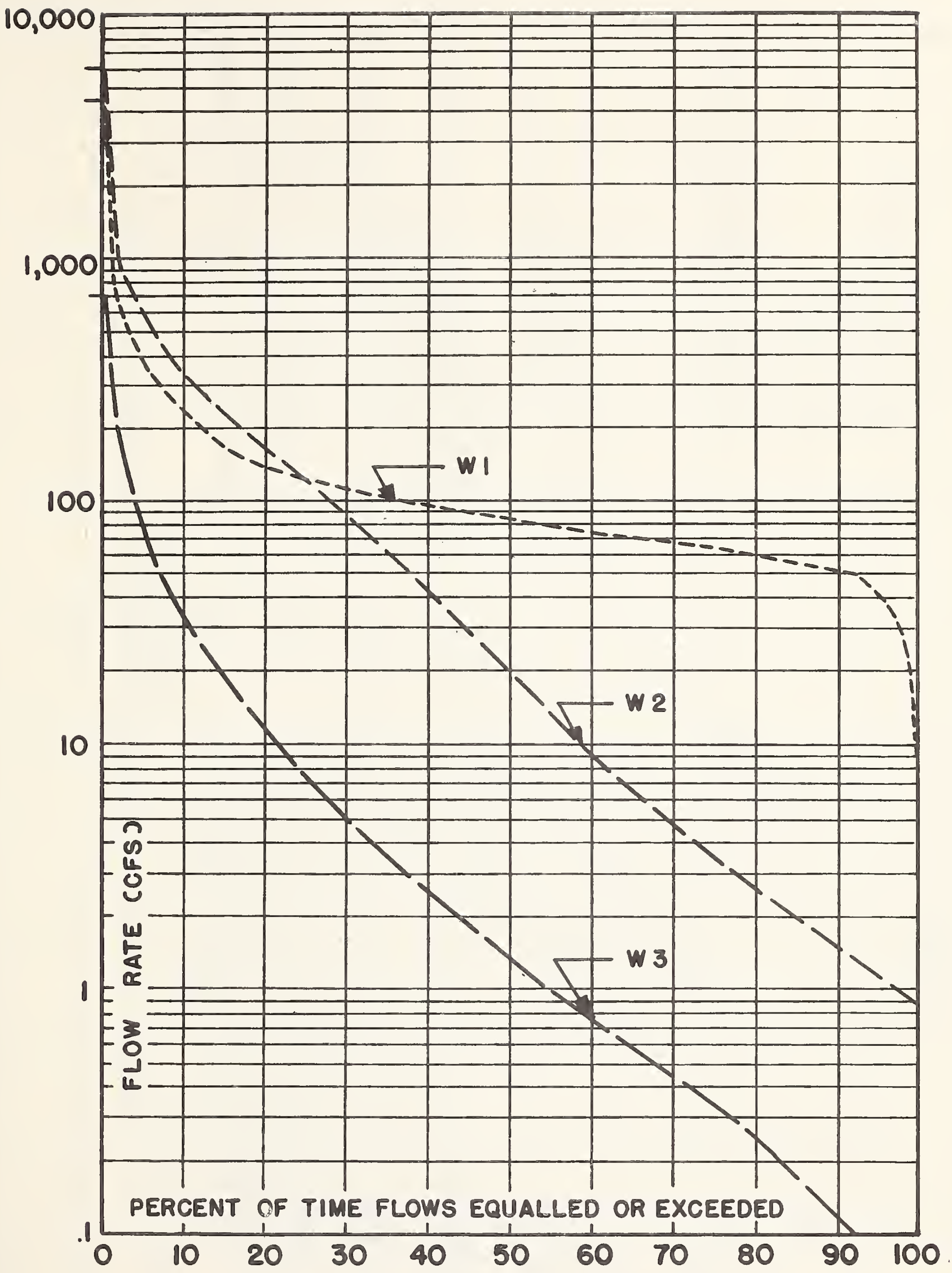


Figure 24.–Flow duration curves–watersheds W-1, W-2, and W-3.

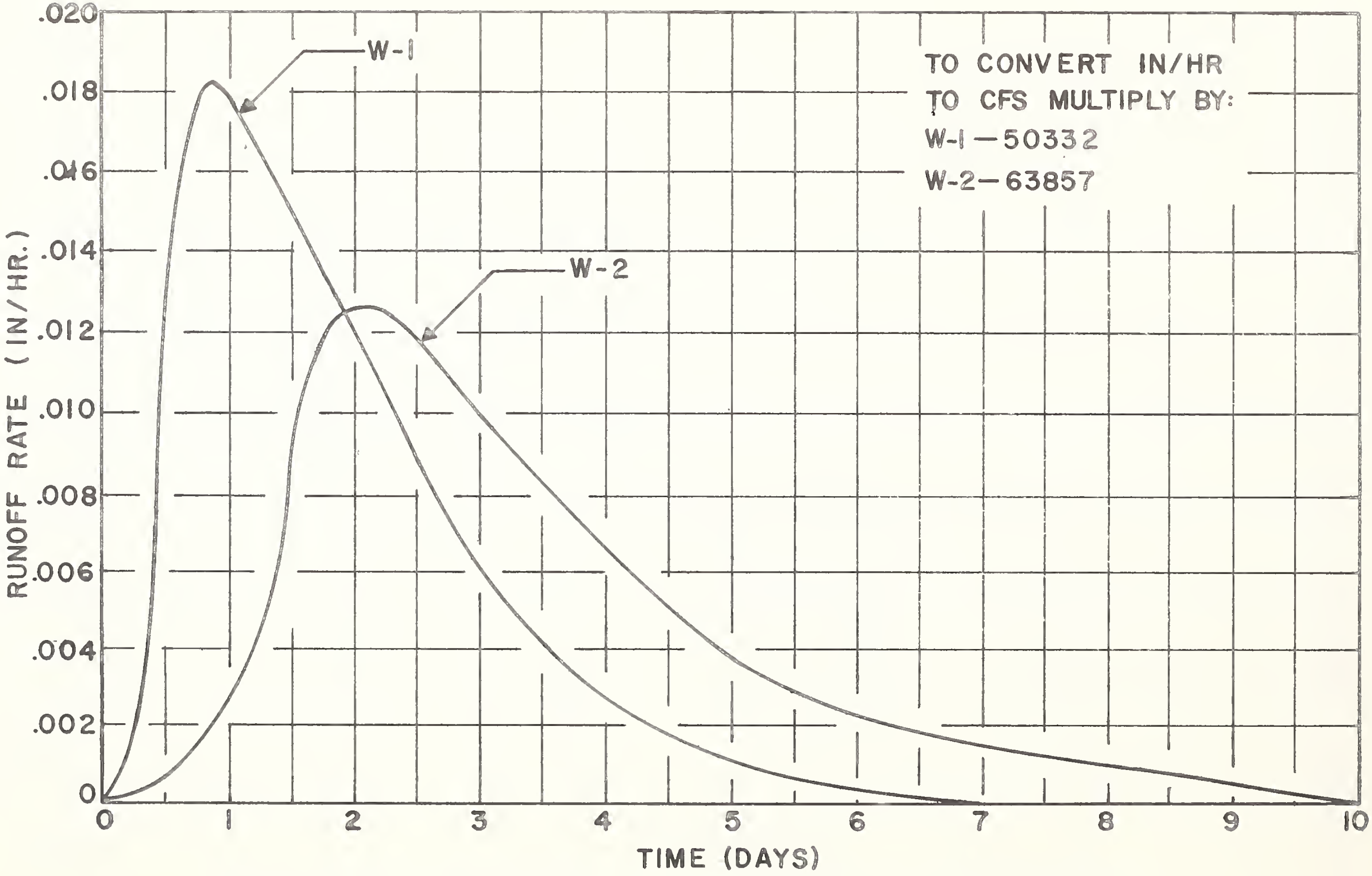


Figure 25.–Twenty-four-hour unit hydrographs, watersheds W-1 and W-2. Each curve is the graphic average of two storms.

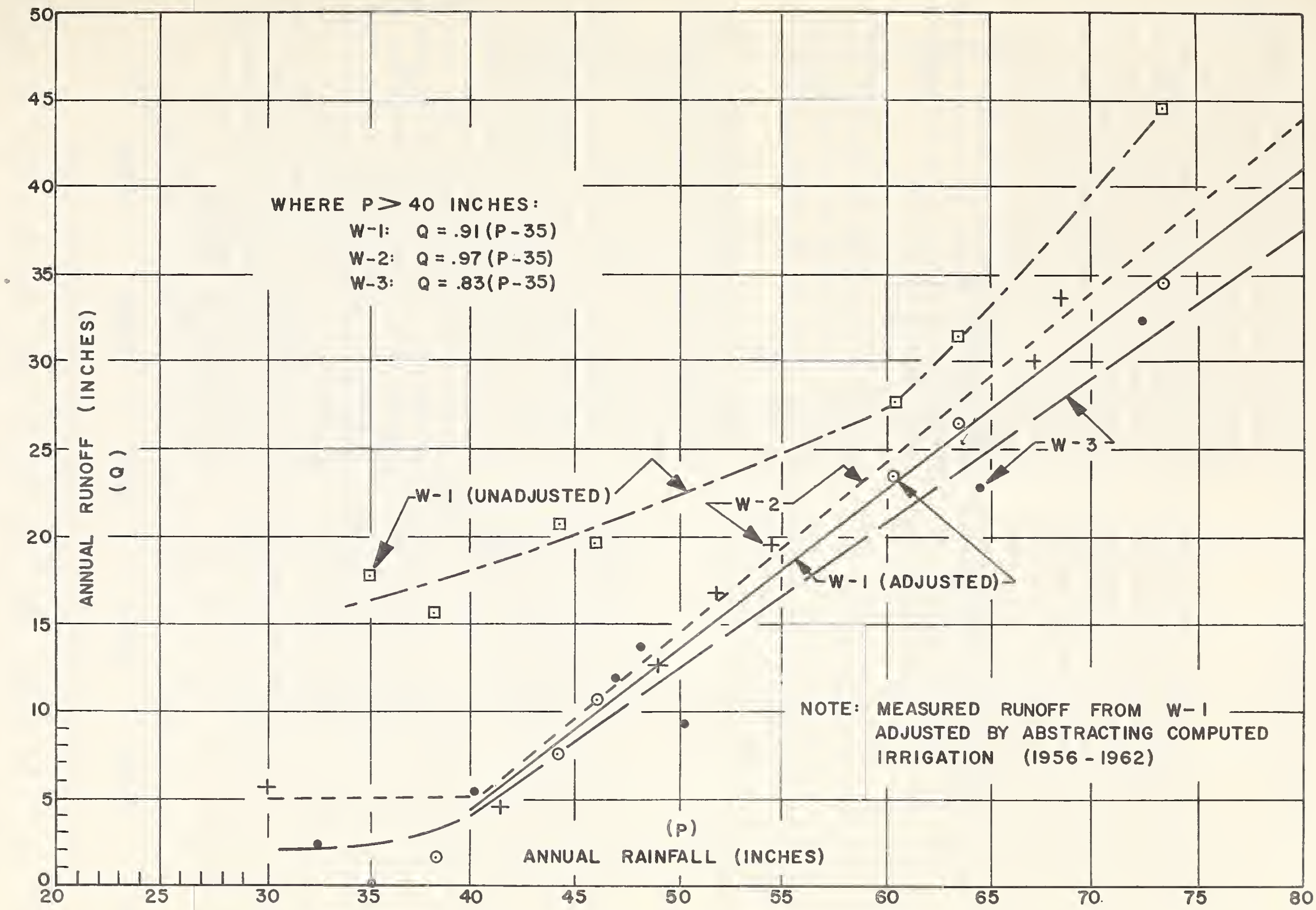


Figure 26.–The effect of annual rainfall volumes on annual runoff, watersheds W-1, W-2, and W-3.

ARTESIAN IRRIGATION

Extent of Use

In watershed W-1, artesian water is used extensively for supplementary irrigation. The actual number of wells is not known and is difficult to estimate because the area is under continuous agricultural and urban development. Some urban wells are allowed to run continuously. To monitor artesian water, two representative wells were capped and equipped with pressure recorders. Continuous records have been kept since 1951. The "north" well is located in a predominantly urban area, and the "south" well is in the agricultural area west and south of Vero Beach. In combination these two wells probably reflect the actual fluctuations in the piezometric pressure within the artesian aquifer.

Daily hydrographs of the two wells clearly delineate the time and extent of artesian irrigation on the watershed. Pressure heads at ground surface have ranged from 22 feet to zero. With continuous land development and the installation of hundreds of additional wells during the period of record, average annual pressures have declined steadily.

Effect on Runoff

Since artesian water could not be measured, an estimate was made by comparing the runoff-rainfall-relations of watershed W-1 with those of W-2. Until 1959 this ratio (runoff to rainfall) averaged 43 percent for W-1 and 30 percent for W-2, under very similar conditions of rainfall, with few periods of limiting soil moisture. A percentage of the W-1 runoff was recognized as inflow from artesian irrigation.

About 1959 the ratio rose abruptly from 43 percent to 55 percent, and since then has approximately maintained this value. Investigations disclosed that numerous additional artesian wells had been installed from 1958-60. Since 1951, the average piezometric levels reflected by the two wells have decreased about 5 feet.

Figure 27 shows the computed artesian inflow during the period 1959-64. The base year 1959 was selected because little change occurred in average artesian water use before that year.

Artesian inflow was estimated using the following procedure: Rainfall and runoff were measured. ET was computed from data from the Upper Taylor Creek Watershed (W-2), where annual computed values for runoff, rainfall, and ET were good. A wet year was selected during which soil moisture seldom limited ET on watershed (W-2). The 36.5 inches of ET on watershed W-2 during this selected year was an estimate of the average ET on W-1, where artesian irrigation presumably prevented soil moisture from significantly limiting ET. Annual ET for W-1 was then adjusted to the ET computed for Taylor Creek by the ratio of ET to measured rainfall, because the two watersheds did not receive equal annual rainfalls. This influence was minor, however, since average annual ET was 36.8 inches prior to 1959 and 36.4 inches after 1959.

Annual artesian irrigation was then computed from the equation: computed ET - (P - Q) = I, where ET is adjusted evapotranspiration, P is measured rainfall, Q is measured runoff, and the residual, I, is computed artesian irrigation.

Before 1959 this computed artesian water usage amounted to 6.2 inches per year. After 1959 this average annual usage increased to 16.7 inches per year—an increase of 10.5 inches per year of artesian inflow.

Hydrographs of artesian pressures were examined; peak demand periods were identified by pressure drops to near zero pressure at ground surface datum, for extended periods. These drops usually occurred in November, December, January, February, April, and May. Zero pressure was assumed to indicate maximum demand. Relatively rain-free periods were selected and compared to runoff hydrographs during these periods of maximum demand. ET was computed for the periods as previously described. Basin storage changes were accounted for as described in the section *Types of Flow*. By applying runoff, rainfall, and ET values to the water budget equation, the residual was assumed to be artesian inflow for the period. From the results, it was estimated that artesian wells could add 0.10 inch per day to the watershed at the end of water year 1964. When the demand period ended, the piezometric head returned to original pressure in about 10 days.

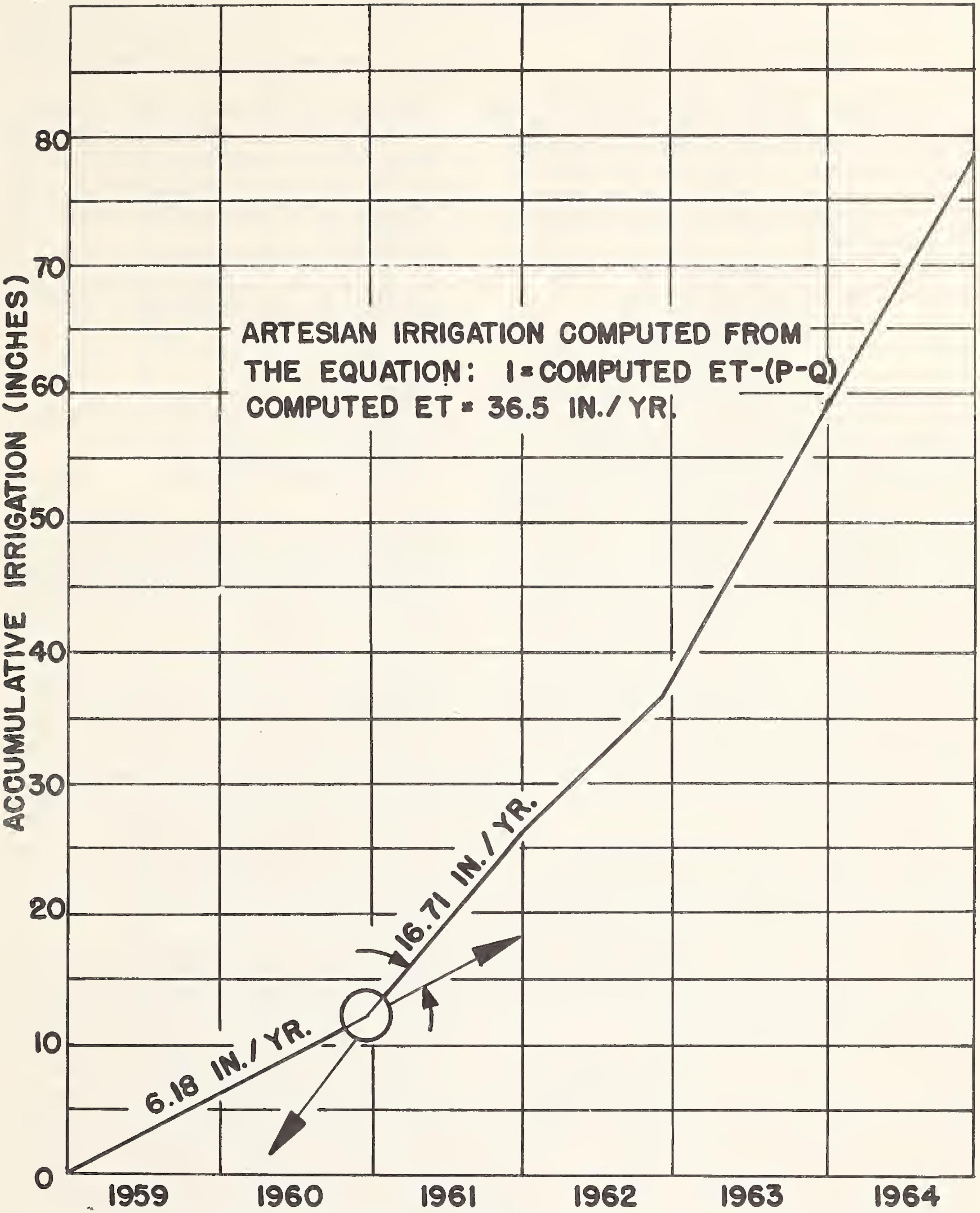


Figure 27.–Accumulative artesian inflow, watershed W-1, 1959-64, where ET is computed, P = rainfall, Q = runoff, and I = irrigation.

METHOD OF COMPUTING

In Florida, solar radiation sets the limits for *maximum* evapotranspiration where soil moisture is not a limiting factor. Rainfall sets the limits of *actual* evapotranspiration because it is the factor that limits soil moisture. In many areas rainfall records are the only hydrologic data available with the exception of USWB pan evaporation data.

Watershed evapotranspiration (ET_W) is computed from the relation: $ET_W = P - Q \pm \Delta S$ where,

P = precipitation,
Q = runoff, and
ΔS = change in soil water storage

Figure 28 shows the interrelation of precipitation (P), runoff (Q), evapotranspiration (ET), and artesian irrigation from inflow (I) for watersheds W-1, W-2, and W-3, 1956-62, as derived from the hydrologic equation.

From the geohydrologic standpoint, W-2 is a sealed unit with negligible deep seepage loss or artesian inflow gain. It can be considered a natural evapotranspirometer. If rainfall and USWB pan data can be related to watershed evapotranspiration, the other water budget component, runoff, can be computed with reasonable accuracy.

Monthly ET_W values were divided by USWB evaporation pan (E_p) values. The resulting ratios (ET_W/E_p) were then plotted against corresponding monthly rainfall measurements. A correlation coefficient, r, of 0.923 was obtained for the regression equation:

$Y = 0.081 + 0.133X$, where $Y = ET_W/E_p$, and X = monthly rainfall

Better correlation resulted when monthly values were converted to seasonal values and plotted against corresponding rainfall values. The maximum value of ET_W/E_p was about 0.78 (pan coefficient for evapotranspiration). This ratio, or pan coefficient, compares with 0.80 developed for the lake to pan ratio at Belle Glade, and 0.70 for the sod to pan ratio derived from the Fort Lauderdale evapotranspirometer studies.

Seasonal differences in ET_W/E_p were observed when the ratios were related to monthly rainfall. When monthly rainfalls during the summer were compared with equal rainfalls in the winter, higher ratios of ET_W/E_p were obtained. This is to be expected because ET would involve a smaller portion of available moisture during the winter, when insolation decreases, than during the summer.

Various seasonal combinations were examined. The ET_W/E_p ratios observed during the cooler months of November, December, January, and February established the better pattern, when contrasted with ratios during the rest of the year.

Figure 29 shows the plotting of these two seasonal curves. They indicate that rainfalls exceeding 3 inches per month during the winter season provided sufficient moisture for maximum ET rates. However, maximum ET during the warmer months required about 6 inches of monthly rainfall.

When watershed evapotranspiration had been determined from these curves, monthly runoff was computed from the basic hydrologic equation $Q = P - ET_W \pm \Delta S$, where

Q = runoff
P = precipitation
ΔS = storage change between beginning and end of month, and
ET_W = calculated evapotranspiration

When heavy rains occurred during the latter part of a month there was above-average water in basin storage at the end of the month not used by ET_W, nor reflected as runoff for the subject month. To account for this excess moisture, a procedure was devised to refine runoff predictions.

The portion of excess rainfall to be carried over into the next month is computed by the following method: rainfall that occurs during the last 3 days of the month and exceeds average daily ET_W values for the month is *decreased* by the average ET_W that occurred on any or all 3 days that the rainfall exceeded ET_W. This value is then added to the next month's rainfall *only* to establish the point on the rainfall ordinate of the water-use curve to determine the corresponding ET_W/E_p value. In most areas data are not available for computing soil moisture storage changes.

Basin water storage was computed from curves previously described (fig. 19), where storage is based on a comparison of runoff rates at the beginning and end of the month. When the runoff rate has *decreased* at the end of the month, ΔS values are positive. When the rate has *increased* at the end of the month, ΔS is negative.

When water tables are deeper than 30 inches on the watershed, basin storage estimates can be in error, because appreciable rainfall, depending on temporal distribution, can occur without reaching the water table or stream channel, thereby having no effect on runoff. Other errors can be introduced when flow rates are taken on rising stages because the basic storage curve was derived from recession flow data. These short term errors are compensatory however.

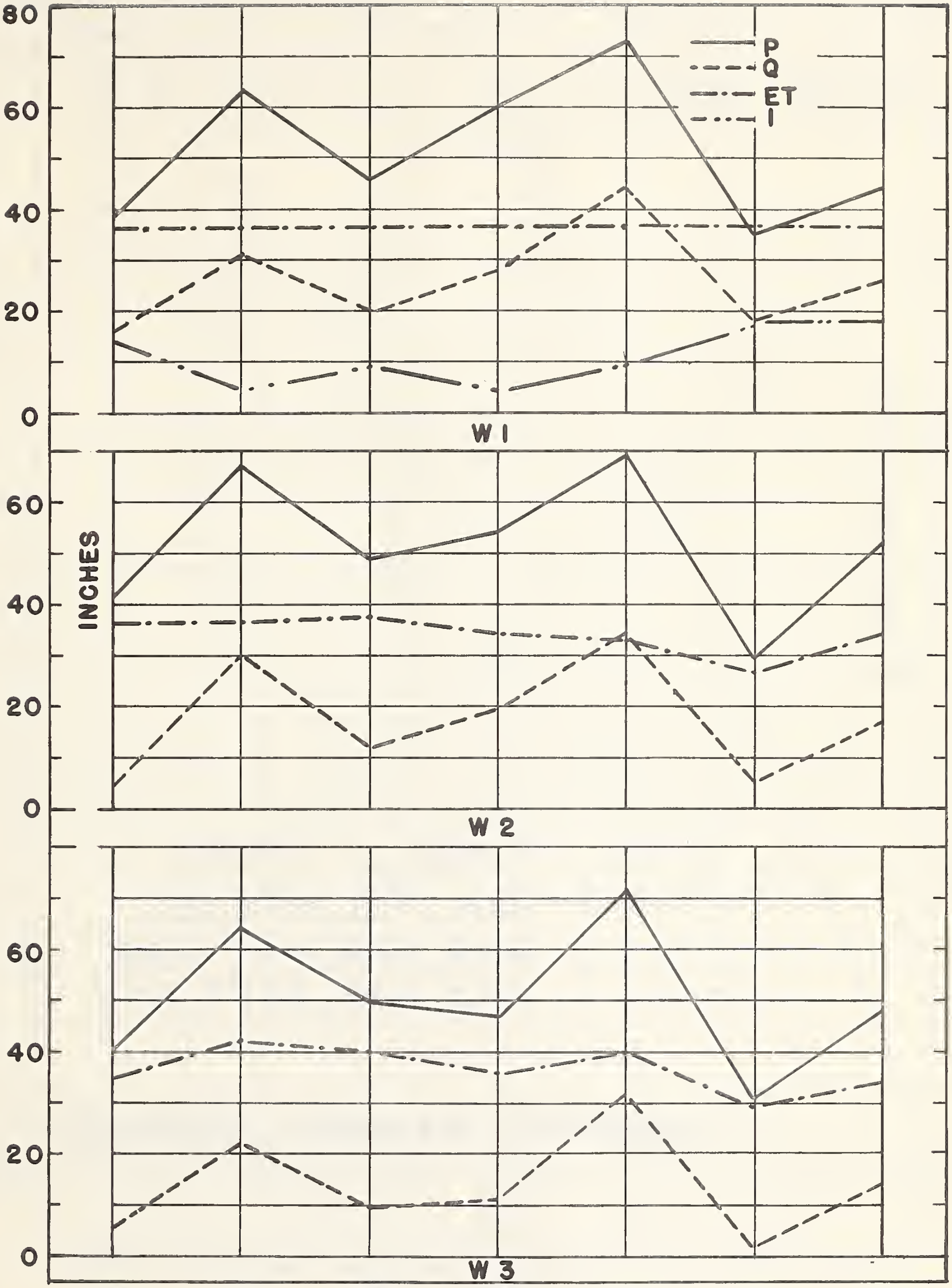


Figure 28.–Water budget components, 1956-62 on watersheds W-1, W-2, and W-3. P = precipitation, Q = runoff, ET = evapotranspiration, and I = irrigation.

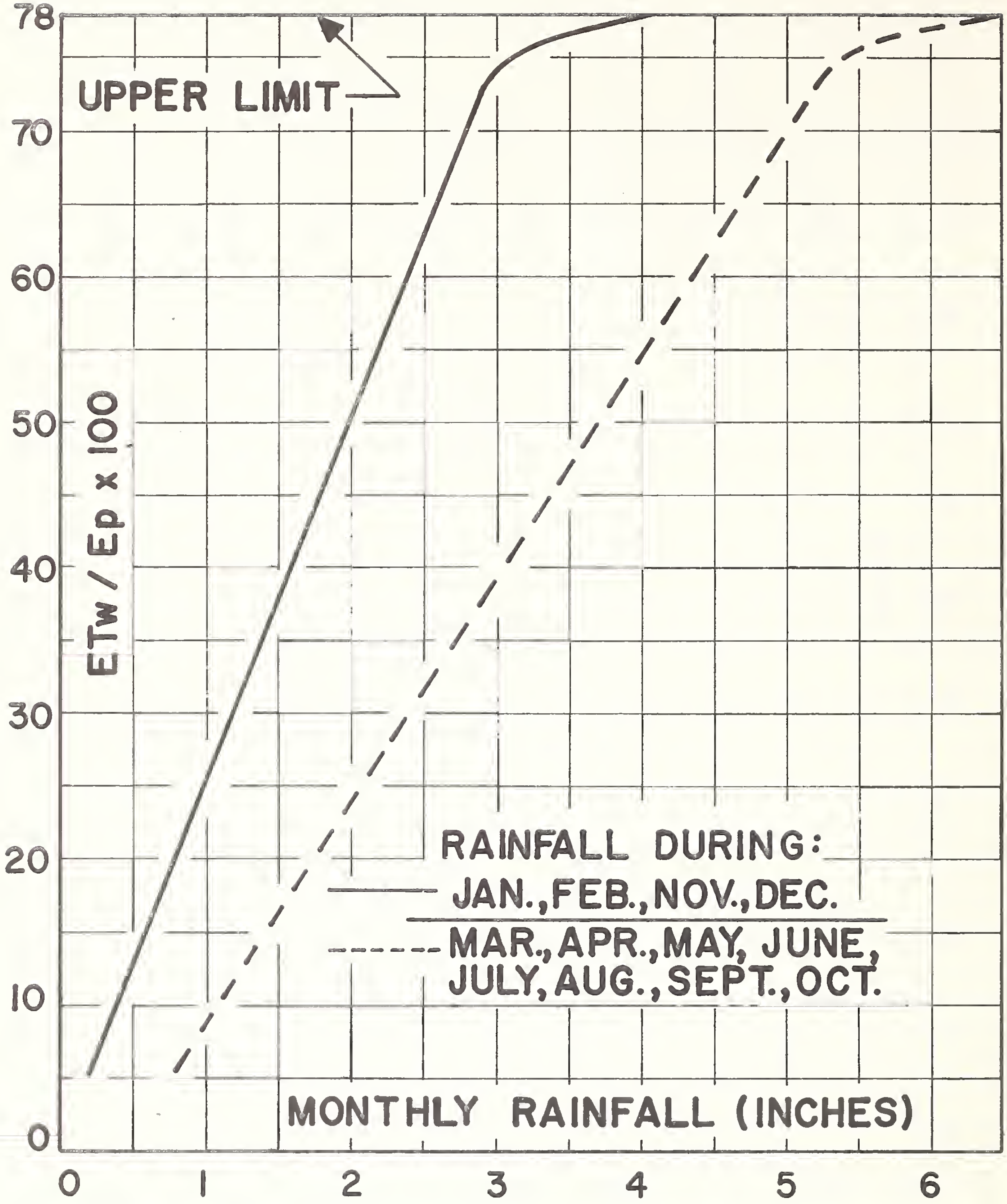


Figure 29.—Seasonal water-use curves for typical coastal plain watersheds in central and southern Florida as determined by monthly rainfall.

Figure 30 shows the accumulative plotting of measured runoff against runoff computed by this method. Measured runoff differed from computed runoff by only 0.98 inch at the end of a 7-year period (1955-62). Table 8 shows the calculations for a typical year (water year 1958-59).

This total accounting procedure can be used to estimate runoff for ungaged watersheds in similar land use areas. However, the change in basin storage (ΔS) must be estimated. The accuracy of monthly runoff estimates will depend to some extent on the accuracy of these ΔS estimates. For longer periods errors will be compensating.

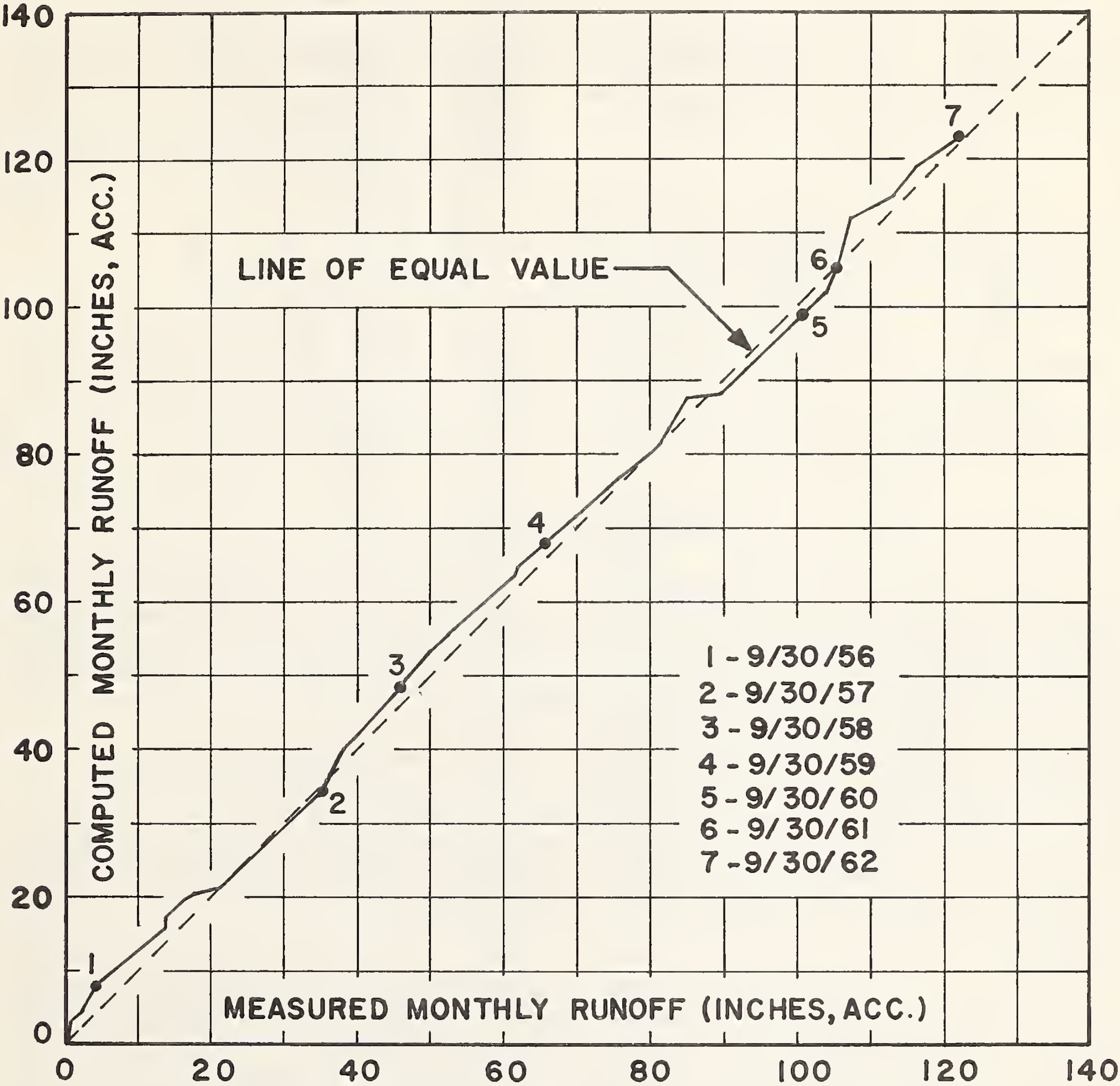


Figure 30.—Measured runoff plotted against runoff computed by the water-use curve, Watershed W-2.

TABLE 8.—*Elements of calculating runoff by the water-use curve method, watershed W-2 (water year 1958-59)*

Months and water year	Rainfall	Δ S	Pan E_p	Rainfall carry-over	Curve ET_w/E_p ratio	Computer ET_w	Computed runoff	Measured runoff
1958	*In.*	*In.*	*In.*	*In.*		*In.*	*In.*	*In.*
Oct.	3.46	+0.10	4.65	0.2	0.50	2.79	0.77	0.49
Nov.	.44	+ .10	3.33	.1	.13	.43	.11	.14
Dec.	2.62	- .50	2.77		.65	1.80	.32	.13
1959								
Jan.	3.26	- .40	3.11	.5	.78	2.42	.74	.48
Feb.	.71	+ .50	3.28	.6	.32	1.05	.16	.30
Mar.	7.48	- .10	4.45	.1	.78	3.47	3.91	3.30
Apr.	2.11	+ .20	5.94	.2	.29	1.72	.59	.32
May	5.49	-1.00	6.40		.75	4.80	-(.31)	.16
June	12.49	+ .40	6.21	1.0	.78	4.84	8.05	9.31
July	6.12	+ .30	6.27	.6	.78	4.89	1.53	1.42
Aug.	3.81	+ .20	5.70	.3	.57	3.25	.76	.75
Sept.	6.38	- .30	4.89	.1	.75	3.67	2.41	2.76
Water year 1959 (total)	54.37	-0.20	57.00			35.13	19.04	19.56

PROGRAM CRITIQUE

Records for the years of observation were dependable where the amount of rainfall was to be estimated. The networks of recording gages provided a satisfactory distribution of gages limited only by terrain and accessibility. Each gage represented a uniformly proportionate area on all three watersheds. Lack of personnel hindered the maintenance of a dense network; but where major storm events were examined, water budget balances showed that rainfall measurements were good. Only local storm rainfalls were not adequately sampled. None of the gages showed an anomalous catch for monthly records. When strong winds were from the south, records from gage No. 2 (Airport) in watershed W-1 were questionable.

Pan evaporation records on watersheds W-2 and W-3 records were excellent. On watershed W-1, records were questionable because the installation was too near the concrete runway of the airport. For that reason pan evaporation from this site was consistently high. The installation has been changed to rectify this condition, and a comparison will be made between the two sites.

Ground water records were good for watersheds W-2 and W-3. The data could be improved by adding several wells at selected sites. The extensive use of artesian water for irrigation on watershed W-1 made the value of ground water wells questionable.

Artesian water use was determined by the water budget method. A fair agreement between artesian pressure fluctuations was obtained at two sites. Obtaining usable wells for this purpose was difficult, but we think the data from the two key wells can be used qualitatively to estimate artesian water use.

Runoff records varied from excellent to poor. Rated channel sections were used by the USGS, and in some instances considerable adjustments had to be made for shifts in canal configuration. This was improved on watershed W-1 by moving the measuring site to a section where hardpan subsoil formed the channel bottom and side slopes.

Before 1962, runoff from W-2 was measured at a section of channel just above the bridge at Cemetery Road. Water hyacinths and floating debris caused difficulties when currents were metered. Despite these difficulties, ratings are considered fair to good.

The wooden weir used for measuring runoff from watershed W-3 caused considerable difficulty. Leakage occurred and washouts sometimes necessitated estimates of flow during periods of major storm runoff. This was later alleviated by using a rated section downstream from the structure.

ARS received outstanding cooperation from the other agencies. The many problems encountered were resolved

with the help of the Central and Southern Florida Flood Control District, SCS, the USGS, Okeechobee County, and other local agencies.

New problems have occurred since 1962 after a PL566 project for watershed protection and flood prevention was developed on W-2 and W-3. The continuing cooperative study should, however, identify the change in watershed regimes from virgin conditions to highly developed agricultural usage with improved water control. The study of watershed W-1 will evaluate hydrologic changes occurring under gradual conversion from agricultural to urban use.

SUMMARY

Three watersheds in the Southern Florida Flatwoods Land Resource Area were compared for topography, drainage characteristics, land use, climate, soils, geology, and hydrology. Parallel comparisons were made for precipitation, evapotranspiration, runoff, ground water, geomorphology, and artesian irrigation on each of the three.

PRECIPITATION

Time distributions of rainfall are established with average monthly values.

To characterize storm rainfall patterns in southern Florida, records of 30 high-intensity rainfalls that occurred on the watersheds are analyzed. Time-distribution patterns are established for storm events of long duration (greater than 12 hours) and short duration (less than 12 hours). Depth-area relationships are determined for both long-and short-duration storms for coastal and inland watersheds. These relationships can be used to adjust point rainfall values to average areal rainfall. Point rainfalls of long return periods occur more frequently at several locations on small watersheds than past predictive formulas indicate.

EVAPOTRANSPIRATION

A linear relationship exists between the amount of sod coverage and evapotranspiration. This is expressed by the function $Y = 0.56X + 44$, where X is the percentage of ground cover and Y is the percentage of potential ET from full cover.

Evapotranspiration from a 36-inch water table is about 88 percent of that from a 24-inch water table. The relationship between evapotranspiration (ET) and open pan evaporation (E) is expressed by the equation $ET = 0.766\ E - 0.011$ in which ET and E are expressed in inches per day. The USWB pan coefficient of about 0.80 can be used to predict annual lake or reservoir evaporation.

Evaporation losses from fallow sandy soils with a water table depth of 12 inches are about the same as lake evaporation; with a 36-inch water table depth they are about 20 percent of lake evaporation.

RUNOFF

Flow volumes are determined for durations of 1 hour, 2 hours, 6 hours, 12 hours, 1 day, 2 days, and 8 days.

Areal depths of water tables are mapped and ground water recession curves are drawn.

Typical desorption and absorption curves are shown for watershed soil profiles.

Ground water recharge with rainfall is expressed by the equation $Y = 0.82X - 0.20$, where rainfall, X, is in inches and water table rise, Y, is in feet.

Limits of rapid flow, intermedial flow, and slow flow are computed and basin water storage curves are established.

The Cypress Creek formula, $\underline{q} = \underline{C}\ \underline{M}^{5/6}$, gives reliable estimates of maximum 24-hour-average runoff rates for small agricultural watersheds wherever rainfall excess can be determined for the maximum 24-hour storm. Values of C in the Cypress Creek formula can be determined fairly accurately from the relationship $\underline{C} = 16.39 + 14.75\ R_e$, where R_e is rainfall excess in inches. Normal rainfall excess can be estimated by subtracting 3 inches from predicted maximum 24-hour storm rainfall.

Frequencies of 7-, 14-, and 30-day minimum flows are determined for watershed W-2.

Flow duration curves are computed for all watersheds.

Unit hydrographs are developed for watersheds W-1 and W-2.

Runoff prediction equations based on annual precipitation are developed for all watersheds.

The extent and expansion of artesian irrigation in watershed W-1 are discussed and methods of estimating this input are described.

A monthly water budget method based on rainfall and USWB evaporation pan records is developed.

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